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Exploring students' iterative practices when learning with physical computing kits through data visualisations

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Declaration of Authorship

I, Veronica CUCUIAT, declare that this thesis, is wholly my own work unless otherwise reference or acknowledged. In addition, I certify that all information sources and literature used are indicated in the thesis. This document has not been submitted for qualifications at any other academic institution.

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Abstract

Physical computing kits allow the practical implementation of open-ended, hands-on, interactive learning experiences in the classroom. In the process of engaging with physical computing kits, students formulate and implement self-constructed goals using an iterative approach. However, the openness and diversity of such learning contexts often make them challenging to design and support. The field of learning analytics has the potential to support project-based learning, using continuous real-time data traces arising from student interactions. Data visualisations, specifically, can provide reflective opportunities for teachers to analyse students' actions and act based on this evidence. However, to date, there has been little data visualisation research targeted at learning with physical computing kits.

This thesis reports progress into the design and evaluation of a suite of data visualisations focussed on students' iterative design process when using physical computing kits in authentic classroom settings. The areas of *iterative design*, *appropriation theory*, *process-driven learning analytics* and *data visualisation* inform the analysis and interpretation of trace data collected from students' interactions.

The contribution of the thesis is three-fold. First, a model for examining students' trace data in keeping with social processes, such as appropriation, is presented. Secondly, insights into the iterative design process of students engaging in open-ended projects are produced, as they emerge from our data visualisations, across multiple groups of students. Thirdly, an evaluation into the role and potential of using data visualisations in the classroom is conducted with ten teachers. Implications for the design and support of open-ended project-based learning experiences with physical computing kits using trace data and data visualisation are discussed based on the teachers' feedback. The thesis represents a first step towards the design of context-aligned, process-oriented data visualisations to provide evidence-based reflective opportunities to support students' iterative design behaviours in this learning setting.

Impact Statement

The impact of the research is two-fold.

First, the thesis makes a practical impact: the findings increase the existing knowledge on how the iterative design process manifests itself in the classroom, in the context of open-ended projects using physical computing kits. The research questions emerged from real-world classroom field work, the data was collected from an authentic long-term project in a London school, and the evaluation was conducted with experienced teachers who already used the SAM Labs kits and were well positioned to inform the research. Teachers can use the thesis' findings on the iterative design process to design learning experiences and support students' iterative behaviours.

Second, the research has impact on data visualisation design: the thesis presents a process-oriented context-aligned approach to designing data visualisations to support guided reflection in open-ended projects using physical computing kits. The approach is positioned as a means of exploring pedagogical concepts, connecting students' actions to learning goals, and exploring what cannot be inferred from the data alone. Researchers interested in the study of students' iterative design or the design of data visualisations in open-ended design learning tasks can build on the insights identified in this research and further explore related aspects.

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LA	**L**earning **A**nalytics
PCKs	**P**hysical **C**omputing **K**its

To Dot

Chapter 1

Introduction

This thesis investigates the use of visual representations to investigate primary students' iterative design processes in open-ended learning activities when using physical computing kits. This chapter is structured as follows: Section 1.1 introduces the context and motivation of the thesis. Section 1.2 presents the research questions. Section 1.3 explains the primary thesis contributions. Finally, section 1.4 offers a summary of the thesis's main chapters and their contents.

1.1 Context and Motivation

Education paradigms are increasingly moving away from static, teacher-led, transmission-based methodologies towards the direction of constructivist, student-centred, growth-based tools and practices (Berland, Baker, and Blikstein, 2014; Cukurova et al., 2016; Fratamico et al., 2017; Kinnebrew, Segedy, and Biswas, 2017). New frameworks such as project-based learning promote the engagement of learners in practical, open-ended, collaborative and highly interactive activities (Cukurova et al., 2016; Berland, Baker, and Blikstein, 2014; Papert, 1993). Project-based learning is positioned as an active process of construction, where students are encouraged to take responsibility for their own learning in practical settings during hands-on activities and derive meaning from their experiences in a personal way (Papert, 1990; Brooks, Brooks, and Alexandria, 1994; Brandt, 1999). Project-based learning activities are designed as open-ended physical simulations of phenomena for children to actively explore and build an understanding of (Papert, 1993).

Physical computing kits lend themselves as appropriate tools to use within project-based learning environments by enabling students to practically engage with abstract learning constructs (Papert, 1993; Sullivan, 2008; Sullivan and Heffernan, 2016). The use of physical computing kits is rooted in constructivist learning theories, as a way of engaging participants more deeply in the learning process and challenge what is counted as learning (Halverson and Sheridan, 2014). Building using physical computing kits also facilitates a quick feedback loop, which allows students to quickly iterate and improve their constructions. Timely feedback encourages student-driven experimentation of alternative approaches, leading to a deep understanding of the practised concepts (Fratamico et al., 2017; Cukurova et al., 2016; Berland, Baker, and Blikstein, 2014; Kinnebrew, Segedy, and Biswas, 2017).

Whilst there is growing interest in using physical computing kits, teachers often struggle to design activities that maximise their potential, and to clearly articulate their benefits and outcomes. There is little consensus over what a well-designed project-based learning activity is and what are the practical implications of implementing it in the classroom (Berland, Baker, and Blikstein, 2014). Teachers find it difficult to design, support and measure the outcomes of project-based activities given the complexity of the environments (Cukurova et al., 2016; Berland, Baker, and Blikstein, 2014; Kirschner, Sweller, and Clark, 2006). Teachers often struggle to support learners navigate open-ended construction tasks without taking away the benefits of these contexts. Furthermore, the evaluation of project-based learning is often retrofitted into traditional evaluation paradigms, which are not representative of the learning objectives targeted by constructivist approaches. Projects are often assessed using the final design students produce, rather than being reflective of the cognitive and development processes that occur during a learning activity (Black and Wiliam, 2010; Resnick et al., 1998).

In response to these challenges, educational research has increasingly focused on investigating skills complementary to academic success, such as problem-solving and self-regulation, which accommodate a more holistic view of the learner that constructivist approaches promote. Iterative design thinking represents one of the learning objectives which emerges directly from students engaging in open-ended problem-solving challenges using physical computing kits. Iterative design is a goal-oriented, non-linear process during which students utilise heuristic reasoning processes to gather information about a problem, and to inform revisions of their solution (Adams and Atman, 1999). The iterative design process forms the basis of any design activity that broadly entails a solution search through a constrained problem space, where the solutions evolve in line with the information generated by the iterative process (Gero, 1990; Hybs and Gero, 1992). From a cognitive theory perspective, iterations are cognitive processes that occur within design activities and change the design state (Ullman, Wood, and Craig, 1990). Given this definition, iterating is a cognitive process central to design problem-solving which can be explicitly analysed, understood, and taught (Dym, 1994). However, there is little research that operationalises iterative behaviours or identifies aspects of iterative behaviour that may contribute to students' improvement.

The fields of learning analytics and educational data mining have the potential to play a significant role in the understanding of project-based learning environments using "continual and real-time assessment on student process and progress, in which the amount of formative feedback is radically increased" (Berland, Baker, and Blikstein, 2014). The dynamic, social and interactive nature of project-based learning is more easily recorded using novel data collection devices and more easily analysed using algorithms able to cope with increased volume and complexity (Berland, Baker, and Blikstein, 2014).

Trace data specifically offers the opportunity to collect and analyse the digital prints of the students' learning journeys. This opens the possibility of aligning data analysis with the philosophical conceptualisation of learning as a process which unfolds over time, assessing performance as part of the activity itself (Molenaar and Wise, 2016). Some researchers have focused on process and the temporal properties of students' activities, as a means of aligning the design of data analytics with the nature of learning as a continuous, dynamic process that evolves over time (Kapur, 2011b). This is aligned with the nature of constructivist learning activities, where the emphasis is placed on the design process rather than on reaching a prescribed output. Analysing temporal characteristics of pedagogical constructs can enhance the explanatory power of what is presented in the data, which is critical in understanding the learning process (Molenaar, 2014). The collection and analysis of trace data enables the focus to be re-prioritised from the end outcome to the process of learning. When the end-goal is unknown, the process becomes the outcome (Gašević, Dawson, and Siemens, 2015).

However, to date, the focus of the learning analytics community has been on computationally-heavy methods of analysing data, such as statistical or AI-powered analyses. These methods require large amounts of data, from multiple sources, and specific, quantifiable dimensions to manipulate into concrete outputs. In contrast, constructivist learning contexts make for complex, interactive, ill-defined open tasks, where multiple learning objectives are at play, and numerous factors may impact student performance, the majority of which are unlikely to be captured from the classroom only (Echeverria, Martinez-Maldonado, and Buckingham Shum, 2019). In response, a limited number of researchers have used data visualisations to inform rather than replace the decision-making process of teachers and students in complex learning contexts, where multiple learning objectives and possible next steps are at play (Bederson and Shneiderman, 2003). Visual representations are aimed at better understanding how learning happens in open-ended contexts, rather than purely generating opaque student models (Kinnebrew, Segedy, and Biswas, 2017). The predominant goal of such data visualisation is to bring awareness of the learning process and complement the discussions between teachers and students (Lang et al., 2017).

This thesis reports progress in the design and evaluation of data visualisations to investigate primary school students' iterative design behaviours when using physical computing kits in open-ended learning contexts. The present research was conducted using SAM Labs physical computing kits (SAMLabs, 2022), as a kit suitable for primary education and already used across several schools in the UK. A design-based research methodology was used to guide the process of designing data visualisations which characterise the iterative design process as an abstract construct, difficult to quantify, situated in real educational settings. The data visualisations are targetted at teachers to create reflection opportunities with their students, building on research which shows that feedback is most effective when information is provided "at process level" (Hattie and Timperley, 2007).

1.2 Research Questions

This thesis explores the main research question of "How can trace data be used to design data visualisations which characterise students' iterative design behaviours to inform student-teacher guided reflection?". The main question is split into three sub-questions:

1. How can trace data be used to visualise the evolution of students' SAM Labs designs?

   The first research question entails a requirements gathering process based on which our data visualisations are designed. The requirements should align with the nature of the learning environment as well as educational theory (Knight, Shum, and Littleton, 2014).

   A first step in formulating these requirements is understanding the learning context, by speaking with teachers and students and observing a variety of open-ended projects employing physical computing kits. Particular attention is paid to the ways in which students test and adapt their constructions, pertinent to the iterative design process as a universal affordance of learning with physical computing kits. The research is contextualised formally in terms of learning objectives and lesson plans as a means of helping teachers scaffold students' iterative design behaviours.

   A second step constitutes the alignment of the trace data with the iterative design process as defined in the research context. Appropriate methodologies are sought to enable a mapping between the information available in the trace data and the students' designs progression. Data visualisations representing students' iterative design process are prototyped, aimed at teachers to better understand and support students' iterative behaviours.

2. How can visual representations of students' evolving designs be used to characterise the iterative design process?

   The second research question explores the insights that can be gained into the students' iterative design behaviours when using visualisation prototypes across multiple students and multiple projects. To account for the limitations of trace data in capturing the entirety of the student learning experience, our evaluation of the prototypes is triangulated with additional qualitative information collected from the classroom. The visualisations are evaluated from the perspective of the questions that emerge around students' iterative design behaviours, which can be further investigated in a reflection process between teachers and students.

3. How can visual representations of students' evolving designs support teachers' understanding of students' iterative behaviours?

Finally, the visualisation prototypes are evaluated with a group of teachers, to understand the potential of such visual representations to inform guided reflection. The suitability of the quantitative proxies embedded within the visualisations is explored, as well as the accuracy of their representation in visual formats. The extent to which data visualisations can help to support students' iterative design processes is investigated with the teachers.

The research questions are summarised in Figure 1.1, at the end of this chapter, alongside the thesis's contributions.

1.3 Research Contributions

The contributions of the thesis comprise insights into the potential of using data visualisations to characterise students' iterative design behaviours when learning with physical computing kits, specifically SAM Labs. The contributions fall into three areas:

1. A context-and theory-aligned approach for the analysis of trace data to identify relevant visual proxies of iterative design

   The first contribution offers a model of arriving at visual requirements to characterise students' iterative design behaviours. The approach aligns the pertinent learning objective – the *iterative design process* (Brennan and Resnick, 2012) – specific to open-ended learning activities using physical computing kits, with the theoretical lens at play – *appropriation* (Poizat, Haradji, and Adé, 2013) – and the information available in the trace data. This contribution responds to the issue of identifying visual proxies from higher order pedagogical constructs, grounded in theory, and responding to the practical use of the physical computing kits in the classroom (Chapter 5).

2. Insights into the nature of students' iterative design during real-world open-ended project-based learning activities using physical computing kits

   This second contribution consists of emerging patterns of students' iterative design behaviours as inferred from the visual proxies across multiple students and projects. Three dimensions are generated as quantitative descriptions of the iterative design process. This contribution assists in the operationalisation of students' iterative design behaviours into quantitative factors to be further explored with students and teachers (Chapter 6).

3. Teachers' feedback on the implications of using data visualisations to support guided reflection during open-ended iterative design tasks

   This third contribution presents the results of the evaluation of our data visualisations with teachers through the social translucence principles of visibility, awareness and accountability (Erickson and Kellogg, 2000). This contribution assists in exploring the role of data visualisations as a medium for teachers to investigate high level pedagogical constructs such as the iterative design process, and their potential to create guided reflection opportunities (Chapter 7).

Figure 1.1 outlines the of the thesis's context, research questions and contributions in connection to each other.

1.4 Thesis Structure

The thesis is structured as follows:

Chapter 2: Background and Related Work

The chapter begins with a description of *physical computing kits*, presenting their definition alongside their educational function. The description is placed in the context of the *iterative design* learning objective. An explanation of *appropriation* follows, as the intersection between learning, goal setting and identity-building, specific to open-ended educational contexts. An argument is made that appropriation is an inevitable component of students engaging with physical computing kits in open-ended learning contexts and should be treated accordingly when analysing iterative design tasks. Next, the existing learning analytics literature available in open-ended design construction tasks using physical computing kits is presented. Common ways of analysing and visualising data in a bid to better support open-ended construction tasks are explored, to inform the visualisation design work undertaken as part of this thesis. The tactics and gaps in designing *data visualisations* which support formative feedback in open-ended design tasks are explored. The extent to which appropriation is accounted for in learning analytics research is considered. Finally, examples of data visualisation studies which highlight the iterations of design work, in a bid to trace the evolution of thoughts and ideas are presented.

Chapter 3: Learning Contexts and Research Methodology

The chapter begins with a description of the SAM Labs physical computing kit, including an explanation of its components and functionality. Next, the two main research learning contexts that were the focus of this research are presented: (i) a set of six weekly code clubs and (ii) a term-long "intelligent" board game project. Each learning context's presentation includes the details of the teaching setting, as well as an illustration of the way in which the SAM Labs kit were introduced and worked with in the classroom. The SAM Labs learning activities are presented alongside the learning objectives targeted in each context. Next, the data which was collected from each learning context in support of the research is presented. Finally, the design-based research methodology used to structure the research into four distinct phases is explained. Each phase is presented in terms of its objectives, the activities which supported its objectives and the main outcomes. The research phases are mapped to the research questions and reflect the make-up of the following chapters of the thesis.

Chapter 4: Visual Representations of Students' Design Iterations

The chapter presents the approach taken to prototype a series of visual representations of the students' SAM Labs designs' evolution. The chapter corresponds to the first research phase intended to answer the first research question: How can trace data be used to visualise the evolution of students' SAM Labs designs? The chapter comprises three sections. First, a description is provided of the ways in which students engage with the SAM Labs physical computing kits in real-life classroom contexts. Characteristics related to the students' iterative design behaviours in open-ended learning challenges are exposed. Second, the practical nature of how students evolve their ongoing construction designs is mapped to the theory of appropriation. The mapping results in a theoretical model which connects the students' exploration of the SAM Labs functionality with the formulation of their construction goals. Third, the use of trace data to prototype a set of visual representations of the students' design iterations is presented. The description of the prototypes is anchored in the learning objectives and the questions formulated around the students' iterative design behaviours.

Chapter 5: Data Visualisations Analysis

The chapter presents an analysis of the data visualisations for the students who participated in the two main learning contexts: the code clubs and the board game project. The chapter explores the second research phase, focussing on the second research question: How can visual representations of students' evolving designs be used to characterise the iterative design process? The findings are presented in three sections. First, a narrative of a selected subset of seven students who participated in the board game project is presented. The video, audio and digital journaling data is matched up with the information presented through the data visualisations. Second, patterns are extracted from the data visualisations from all the students across the two learning contexts. Third, three dimensions of students' construction behaviours are presented as traits that become consistently apparent when characterising the students' design iterations using the data visualisations: variety, validity and complexity. These dimensions are cross-checked with existing research on iterative design.

Chapter 6: Teacher Evaluation

The chapter presents the results from ten interviews with teachers asked to evaluate our prototype data visualisations. The chapter corresponds to the third research phase, focussing on the third research question: How can visual representations of students' evolving designs support teachers' understanding of students' iterative behaviours? The chapter starts with an explanation of the social translucence framework that was used to structure the interviews and frame the teachers' answers. Next, the interview results are presented in three sections. First, the teachers' background and experience are presented to provide context for their feedback. Second, the impact of viewing the information presented by the data visualisations on teachers' interpretation of students' SAM Labs constructions is discussed. Third, the teachers' feedback on each different data visualisation is analysed in terms of the three dimensions of the social translucence framework: visibility, awareness, and accountability.

Chapter 7: Conclusions, Limitations and Future Work

The chapter corresponds to the fourth and final research phase, discussing the implications of providing teachers with visual representations of students' evolving SAM Labs constructions to support the iterative design process in open-ended learning settings employing physical computing kits.

The current chapter covered the context and motivation of the thesis, the main research questions alongside contributions and a summary of the remaining of the thesis's content. The following chapter presents the existing research which informed the present thesis and form the foundations of the thesis's contributions.

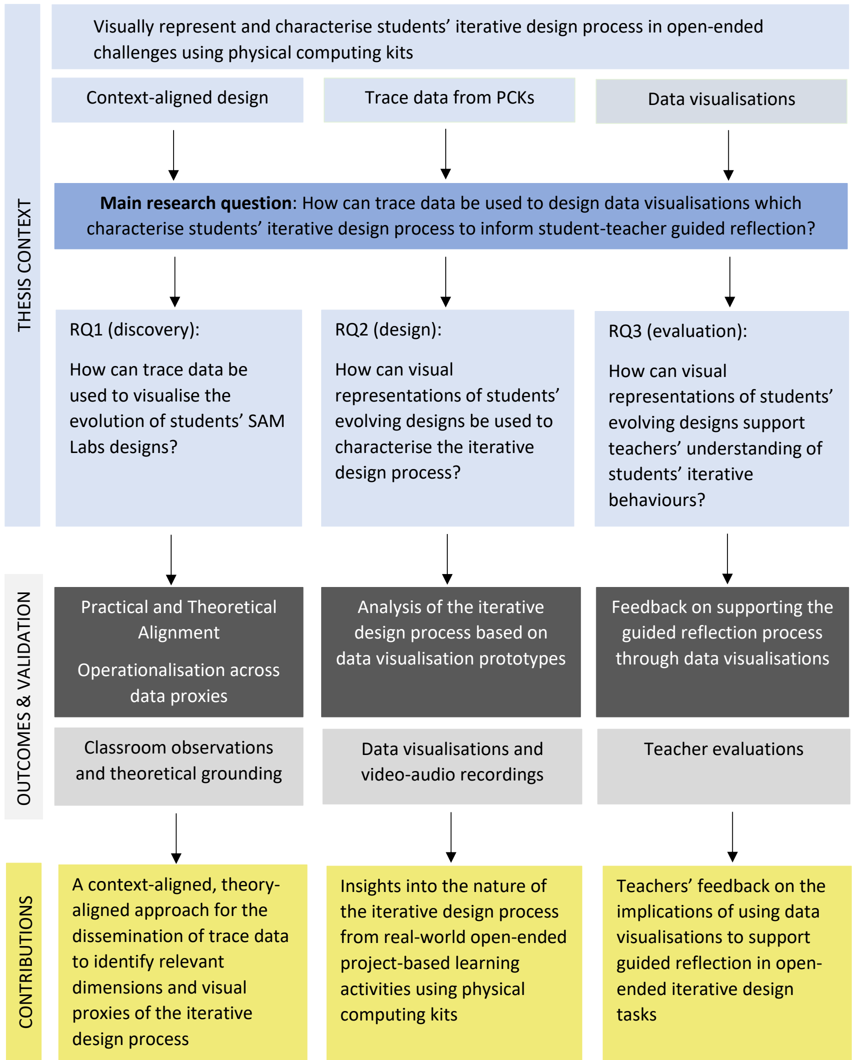


FIGURE 1.1: Summary of the thesis's context, research questions and contributions

Chapter 2

Literature Review

This chapter presents the background and related research that motivated the present study. First, physical computing kits and their role in educational contexts are explored. The iterative design process is identified as a unique learning objective emerging from open-ended learning activities using physical computing kits. The iterative design process is contextualised within appropriation theory to inform the analysis of data collected from students' activities. Next, the potential of using trace data, which tracks the changes students make to their physical artefacts, to investigate students' iterative behaviours is examined within the broader learning analytics research. The suitability of different learning analytics methodologies is explored in relation to the nature of the learning context. Data visualisations are highlighted as supporting tools that can enhance the decision-making capabilities of students and teachers with increased evidence. Research questions are formulated with regards to the specific ways in which data visualisations might be designed to support students' iterative design process, in close alignment with the characteristics of the learning context.

2.1 Introduction

Physical computing kits enable the practical implementation of constructivist theory in the classroom (Resnick and Silverman, 2005). Their transparency and interactivity allow students to "learn through designing" (Resnick and Silverman, 2005; Gaudiello and Zibetti, 2013). Designing entails engaging with a problem in an iterative way, where building blocks are used to explore a problem space and refine a series of prototypes towards a final construction (Kafai, Resnick, and Matusov, 1997).

Open-ended, hands-on, engineering design tasks offer students the chance to externalise their own interpretation of cognate construction principles, test perceived possibilities and act on resulting feedback. The open-ended aspect of project-based learning is explored in educational theory literature via the concept of appropriation (Wertsch, 1991), as the self-constructive component of the learning activity. By formulating their own goals in open-ended projects, students are appropriating the knowledge and the tools they are interacting with for their own purposes (Wertsch, 1991; Poizat, Haradji, and Adé, 2013; Tchounikine, 2017). Appropriation is intrinsically linked to learning through designing, with physical computing kits standing in for "objects-to-think-with", and students' constructions becoming reflections of their ideas and means to engage in a reflective process (Schön, 2017; Harel and Papert, 1991).

The nature of learning through designing entails engaging with "wicked" problems (Resnick and Silverman, 2005; Gaudiello and Zibetti, 2013), for which trial-and-error and design thinking are an important part of the problem-solving process. Rather than a neat, linear activity, the design process often reflects "messy" learning contexts, resolved through optimisation and trade off (Barak, 2020).

The iterative design process is a specific learning objective targeted in open-ended learning activities using physical computing kits, at the basis of learning by designing (Resnick and Silverman, 2005). It is defined as the cycle of prototyping, testing, and revision, that requires students to engage in a continually adaptive process, throughout the course of creating a computational artefact, where one's goals "might change in response to approaching a solution in small steps" (Brennan and Resnick, 2012, pp.7). The iterative design process is often supported and evaluated using documentation showcasing students' evolving constructions, through journals, portfolios, exhibitions or presentations (Barak and Doppelt, 2000). However, these are incomplete records of activity, which only partially reflect the students' efforts, which students often feel reluctant to document, and are often disregarded as inconvenient or distracting (Barak, 2007).

The iterative design process can also be observed through the changes students make in their projects, such as improvements to their circuit diagrams, changes in the code or alterations to the physical artefacts (Fields, Lui, and Kafai, 2019). Trace data generated by the students' actions using physical computing kits records the changes students make to their artefacts in a non-invasive manner (Malmberg, Järvelä, and Kirschner, 2014).

However, computational analysis requires deterministic, quantitative dimensions to manipulate into concrete outputs, which abstract educational constructs are difficult to translate into (Echeverria, Martinez-Maldonado, and Buckingham Shum, 2019). In addition, most studies are limited to virtual on-screen interactions as a means of containing the data collection and analysis context, not reflecting the nuances of classroom social complexity (Gašević, Dawson, and Siemens, 2015). In contrast, student-centred exploration of open-ended hands-on learning tasks has been less studied. This is due to both pedagogical challenges of implementing constructivist-inspired methodologies in the classroom, as well as the challenges of collecting and analysing meaningful data (Blikstein and Worsley, 2016). A few research studies have proposed an event-centred view of the learning process as a way of more closely linking quantitative approaches to the dynamic nature of learning constructs and how these unfold over time (Molenaar, 2014). Underpinning the focus on process and temporality is the understanding that learning is a continuous, dynamic process that evolves over time (Kapur, 2011b).

Specifically, data visualisations are instruments that can capture the learning events recorded in trace data and can empower students and teachers with increased evidence of their actions represented in educationally meaningful ways (Bederson and Shneiderman, 2003). Example studies use visual representations to show the evolution of design work and explore irregular activities of students in messy learning contexts (Yan, Hu, and Piech, 2019; Yan, McKeown, and Piech, 2019; Kapur, 2011a). The extent to which changes between consecutive iterations from students' building with physical computing kits can constitute units of analysis for visualising and supporting students' iterative design process is reflected in the emerging research questions that are presented in the concluding section of this chapter.

2.2 Learning with Physical Computing Kits

According to constructivist theories, true learning emerges from students' experiences and actions in the world (Piaget, 1970a). The role of physical computing kits within constructivism is rooted in Papert's constructionist theory. Papert used the "Logo-Turtle" mobile robot to practically apply Piaget's theoretical ideas, arguing that technologies are uniquely placed to provide suitable learning environments where students can construct a deep understanding of the world (Papert, 1990).

Project-based learning emerged as a pedagogy founded on constructivist ideas, alongside other similar approaches such as problem-based learning, discovery learning, inquiry learning, experiential learning, active learning or student-centred learning (Savery, 2015). Whilst these present nuanced differences, they converge around the target conditions they provide for learning to happen. These conditions involve treating learning as an active process of construction, where students are encouraged to take responsibility for their own learning in practical settings during hands-on activities and derive meaning from their experiences in a personal way (Papert, 1990; Brooks, Brooks, and Alexandria, 1994; Brandt, 1999. Using physical computing kits in open-ended project-based learning activities enables the practical implementation of constructivist theory in the classroom, with students using building blocks to work through open-ended problem spaces and generate a variety of solutions.

2.2.1 Physical Computing Kits Definition

Physical computing kits, also known as robotic construction kits, physical manipulatives, cybernetic construction kits or programmable bricks (Resnick et al., 1998; Sullivan and Heffernan, 2016), are tools used to facilitate the practical, hands-on experiences integral to project-based learning contexts. Physical computing kits have on-board computing capabilities, such as LEGO Mindstorms robotic kits, programmable beads, and other toys with embedded computers (Resnick et al., 1998). Children build and program artefacts which can interact with the surrounding environment. Using components such as actuators (motors, lights) or sensors (e.g.: motion, touch, and rotation sensors), students program the devices to generate specific programmed responses. A typical activity involves students building a car that uses a light sensor to follow a coloured path on the floor. Designing such artefacts involves building prototypes to test ideas and iteratively progress through different models (Resnick, Berg, and Eisenberg, 2000; Resnick, 1996b; Resnick, 1996a; Bers and Urrea, 2000).

Physical computing kits research consistently highlights two main inherent features which give them their unique potential for learning: transparency and interactivity (Gaudiello and Zibetti, 2013).

Transparency refers to the open and accessible programmability of target behaviours. The openness designed within the kits is defined in equal measure by the functionality boundaries it presents students with, as well as the freedom of exploration within these boundaries. Mitchel Resnick talks about supporting "multiple pathways" towards learning, inspired both by Papert's work on Logo as well as his own work on Scratch and other construction kits (Resnick and Silverman, 2005; Rusk et al., 2008). Papert considered that the success behind Logo graphics was not the performance it got from learners, but the power it gave them (Papert, 1993). Mitchel Resnick makes a clear distinction between pure building tasks, such as putting together a Harry Potter LEGO kit, and the process of an open design of artefacts by using underlying principles of construction. To allow for such design learning activities, he points to the "low floor and wide walls" principle which allows for a low entry point for novices to get started, as well as a wide diversity of thinking pathways for students to apply to their constructions. He considers the similarity of creations amongst student outcomes a failure, while diversity as an indicator of success (Resnick and Silverman, 2005).

Interactivity points to the immediate feedback given on execution. It is perhaps the responsive nature of project-based environments that contributes most to the shift from teacher-centred to learner-centred education. In a highly responsive environment, students can proactively explore different options rather than passively await the teacher's instructions. This enables learners to act as creators rather than consumers of knowledge (Papert, 1993). Piaget also singled-out practical activity as a main prerequisite of any learning environment (Piaget, 1970b). It is the responsiveness of hands-on practical activities which make these suitable vehicles for learners acting upon their own understandings and receiving prompt feedback. Physical constructions of artefacts engage all our senses, contributing to the creation of knowledge through the actions we perform - sensory-motor acts, language acts, and logical acts (Piaget, 1970b). The two distinct features give physical computing kits their unique learning potential in comparison to either analogue or fully virtual learning tools (Gaudiello and Zibetti, 2013).

2.2.2 Role of Physical Computing Kits in Education

Physical computing kits are positioned in literature as external representations of mental concepts that help reflect the abstract knowledge construction process (Katterfeldt, Dittert, and Schelhowe, 2015). The kits enhance analogical and embodied cognition, as well as introducing additional modes of learning including iterative problem-solving cycles, discussion and reflection given their quick feedback loop (Sullivan and Heffernan, 2016; Papert, 1993; Sullivan, 2011). Physical computing kits become "objects-to-think-with" rather than "about", positioning students as designers of concrete objects (Harel and Papert, 1991).

Physical computing kits sit at the centre of the Maker Movement, defined through open-ended, hands-on, engineering design tasks (Blikstein and Krannich, 2013). These open-ended tasks are becoming increasingly prevalent in both K–12 and post-secondary learning institutions, as educators are adopting this approach to teach students real-world science and engineering skills (Worsley and Blikstein, 2014).

The use of the SAM Labs blocks in the present research also builds on the human-computer interaction (HCI) literature of designing effective learning experiences using physical computing kits. Broadly, Dix and Gill position physical computing at the centre of several HCI strands including tangible interaction, ubiquitous computing, and spatial/mobile systems (Dix and Gill, 2018). They argue that the use of physical computing kits underpins embodiment and experiential approaches, which are complementary to different facets of human experience with physically embodied digital technology (Dix and Gill, 2018). Specific benefits of using physical computing kits in education are highlighted by (Lechelt et al., 2016; Johnson et al., 2016; Horn, Crouser, and Bers, 2012; Zuckerman, Arida, and Resnick, 2005) amongst many others. For example, Lechelt et al.'s study presents ConnectUs, an IoT toolkit used to introduce children to IoT concepts, including opportunities for children to design their own IoT systems (Lechelt et al., 2016). Building on playful learning and constructivist theories, they argue that students interacting with tangible interfaces can help children better understand and engage with abstract concepts (Lechelt et al., 2016). In continuation to their research, they argue that physical toolkits can support learning for special education needs (SEN) students and increase the accessibility of computing education amongst a diversity of learners (Lechelt et al., 2018).

Johnson et al. investigate the impact of computational making on children of different ages, with the results showing improved performance for younger learners were the taught concepts were less known (Johnson et al., 2016). Improvements were identified in terms of knowledge acquisition, engagement with learning, creative appropriation, and collaboration between students during the making activities (Johnson et al., 2016). In their study, Horn et al. discuss both the advantages and disadvantages of using tangible computing kits in educational contexts and advocate for a hybrid approach to meet the needs of specific learning experiences (Horn, Crouser, and Bers, 2012). They argue that physical blocks can be effectively complemented by graphical interfaces which build on each other and that teachers and students can toggle between depending on the learning situation (Horn, Crouser, and Bers, 2012). Zucherman and Resnick look specifically at the use of digital manipulatives for engaging young learners with abstract structures of dynamic behaviours. They find that Montessori-inspired manipulatives are accessible and engaging for young students to engage in an iterative process of hands-on modelling, simulating and analogizing (Zuckerman, Arida, and Resnick, 2005). Katterfeldt et al. summarise the three core ideas which facilitate "Bildung", deep and sustainable learning using programmable bricks: be-greifbarkeit (being 'graspable'), imagineering and self-efficacy (Katterfeldt, Dittert, and Schelhowe, 2015). Horn et al., Zucherman and Resnick and Katterfeldt et al. provide specific design guidelines which help learning experiences using physical computing kits effectively engage learners with the target learning objectives (Horn, Crouser, and Bers, 2012; Zuckerman, Arida, and Resnick, 2005; Katterfeldt, Dittert, and Schelhowe, 2015).

Despite a consensus around the educational potential of using physical computing kits, there are significant challenges hindering their practical implementation in school contexts (Blikstein, 2015). For instance, Kirschner, Sweller and Clark write about the failure of constructivist-oriented methods due to the difficulty of novice learners engaging effectively in minimal guidance contexts (Kirschner, Sweller, and Clark, 2006). In response, researchers have highlighted the importance of learning design to tailor the scope and complexity of tasks, as well as providing suitable scaffolding to enable students to learn in complex domains (Hmelo-Silver, 2004; Hmelo-Silver, Duncan, and Chinn, 2007; Savery, 2015). Likewise, in their studies of children learning with robotics kits, Gaudiello and Zibetti warn against taking the kits' educational potential for granted (Gaudiello and Zibetti, 2013).

Instead, their potential can only be achieved when synchronised with the cognitive strategies students use when building with the kits (Newell, Simon, et al., 1972). Despite the promise of learning analytics research to help better tailor learning experiences according to individual learners' needs, research supporting the cognitive strategies required to leverage the educational potential of using physical computing kits has largely been missing from the learning analytics community (Blikstein, 2015).

In the next section, appropriation is explored as an integral part of students' engagement with physical computing kits. Appropriation, when accounted for in the design and analysis of open-ended design tasks, can maximise the potential of such environments and allow students to maximise their benefits.

2.3 Appropriation

2.3.1 Appropriation Definition

Open-ended, hands-on, engineering design tasks offer students the chance to externalise their own interpretation of the ideas they are exposed to, associate them with previously existing concepts and in that process, expand their corpus of personal understanding. The open-ended aspect of project-based learning is explored in the educational theory literature via the concept of appropriation, as the self-constructive component of activity (Poizat, Haradji, and Adé, 2013). Appropriation refers to an individual's act of repurposing the actions of others for their own use (Poizat, Haradji, and Adé, 2013).

In relation to the adoption of pedagogical tools such as physical computing kits, appropriation is situated as the developmental process that "comes about through socially formulated, goal-directed and tool-mediated actions". Wertsch argues that the students' active role in this developmental process is fundamental to appropriation (Wertsch, 1991). By formulating their own goals in open-ended projects, students are reconstructing the knowledge and the tools they are interacting with for their own purposes (Grossman, Smagorinsky, and Valencia, 1999).

2.3.2 Role of Appropriation in Education

Polman's study investigates the use of media tools in understanding history concepts, and the role they play in allowing students to appropriate the content in a way that is linked to their identities. He argues that in classrooms and code clubs, cognition gets so intertwined with identity development that studying one in isolation of the other leads to an incomplete analysis of such environments (Polman, 2006). Polman positions project-based learning pedagogies as specific strategies in which educators design for appropriation and integrate them into their classrooms, using them to nurture students' drive for learning (Polman, 2006).

Considering appropriation for learning contexts might redefine what are considered as "effective" or "positive" behaviours or actions (Maxwell, Weill, and Damico, 2017). In their study, Maxwell et al. use appropriation to analyse the writing of children with autism. They point towards a "strength-based" interpretation of behaviours, which is more congruent with the idea that when writing, students are expressing themselves, even if some behaviours might seem ineffective or repetitive from a purely effective writing process. They point to an increasing amount of educational research into strength-based interactional frameworks, which show that some repetitive actions which would normally be considered indicative of "unproductive" behaviours are in fact strategic communicative function (Damico and Nelson, 2005; Maxwell, Weill, and Damico, 2017). In this vein, Maxwell et al. describe their analysis of students writing as: "Writing was viewed not as a purely mechanical act, but as a symbolic tool used to mediate interactions with the world" (Maxwell, Weill, and Damico, 2017).

Despite appropriation being a fundamental part of learning, the construct has been largely absent from current education technology research, and is yet to be operationalised in a way that can be considered in learning analytics research.

Next, appropriation is contextualised in Design-Based Learning, as an approach to learning which intrinsically allows students to appropriate the tools and ideas they engage with. The nature of design problems is further detailed, and the iterative design process is identified as a primary learning objective in Design-Based Learning. Finally, the iterative design process is presented in connection to appropriation, in the way that it emerges when learning by designing.

2.4 Iterative Design

2.4.1 Appropriation and Design-Based Learning

Designing pedagogical tools for appropriation promotes a "designerly" approach to learning (Katterfeldt, Dittert, and Schelhowe, 2015). Treating physical computing kits as "objects-to-think-with" that students design with leads to their resulting artefacts becoming reflections of their ideas and a means to engage in a reflective process (Schön, 2017). This process of "constructing meaning" with tangible objects is positioned by Kafai and Resnick (Kafai, Resnick, and Matusov, 1997) as a core process of design theory as well as constructionist theory. The product outcome itself is not the main focus, but rather the reflective process of designing it.

Höök discusses the activity-centric implications of educational technologies for appropriation through design-based learning (Hook, 2008). She describes technologies as "surfaces" that are left open for learners to appropriate during their design activities, instead of learning dictated in a strictly instrumental manner (Hook, 2008).

In his exploration of design thinking, Cross zooms into designers' ability to appropriate the design brief, which is equivalent to the continuous reflective process of both the problem and the solutions as they co-evolve during the design process (Cross, 2011). From this perspective, design thinking is aligned with the way in which digital fabrication tasks take place in educational settings (Smith, Iversen, and Hjorth, 2015; Kafai, 2012; Blikstein and Krannich, 2013). Smith et al. refer to the development "sense of quality directed at the process" to describe some of the design choices made based on the "right feeling" designers often turn to when solving problems (Smith, Iversen, and Hjorth, 2015). Whilst acknowledging the unreliable or even irresponsible way of characterising their thinking process, the authors argue that experiencing all possible failures eventually leads to the development of designers' understanding of quality. As a result, they position failure and experimentation as essential parts of digital fabrication (Smith, Iversen, and Hjorth, 2015), in line with Martin (Martin, 2015) and Blikstein (Blikstein, 2013).

Ribeiro articulates the need for an "autonomous" attitude from students when engaging in robotics projects, their capability to use previous knowledge and experiences to search for solutions and develop problem-solving heuristic strategies (Ribeiro, Coutinho, and Costa, 2011). They highlight design activities as appropriate environments provided by robotics education where students feel safe and empowered to practice their autonomy and apply their own ideas. In the process of searching for appropriate solutions in "autonomous" ways, students appropriate the emerging designs as well as the materials and tools available to them (Ribeiro, Coutinho, and Costa, 2011; Smith, Iversen, and Hjorth, 2015; Hook, 2008).

In the context of students constructing using physical computing kits, appropriation is positioned at the intersection between students' self-made goals and their design activity, which get continuously adapted in relation to each other as the students complete their constructions.

2.4.2 Design Problems

Smith et al. make a direct link between design thinking and the process of creating, ideating, and reflecting students go through in digital fabrication environments (Smith, Iversen, and Hjorth, 2015; Cross, 2006; Cross, 2011; Nelson and Stolterman, 2014). In line with Resnick and Ocko (Resnick, Ocko, et al., 1990) and Ribeiro et al. (Ribeiro, Coutinho, and Costa, 2011), they single out the ill-defined nature of "wicked" problems (Buchanan, 1992) for which design thinking and trial-and-error exploration informed by insights and past experiences are an important part of the problem-solving process (Smith, Iversen, and Hjorth, 2015). Specifically, Cross emphasises the continuous redefinition of the problem itself, considering the experiments conducted during the design process (Cross, 2011). It is not only the solution and the way of using available functionality that changes in order to reach an envisaged goal, but also the problem itself and its target solution (Smith, Iversen, and Hjorth, 2015).

Johnsey is the author of a comprehensive study which reviews published models for the design process typically employed in technology design-related tasks in classrooms across England and Wales (Johnsey, 1995). He posits a challenge to the wider community in his concluding question on whether a design process even exists. In his review, he observes that most problem-solving frameworks tend to converge, with some variety, around the same linear steps, describing "a procedural path which can be broken down into a developmental sequence consisting of a number of related areas of activity" (Johnsey, 1995, pp.201). Whilst these can be useful starting points which offer a tidy and simplistic model of messy learning contexts, which help teachers approach the design and technology parts of the curriculum, they are also in danger of perpetuating a mythical view of reality. He also observes that current models have little relation to grounded, direct, systematic observations of pupils as they design in a wide range of situations and contexts (Johnsey, 1995). Many of the proponents of fixed linear or cyclical problem-solving sequences caution over similar caveats regarding their practical use in the classroom (Education and Science, 1987; Kimbell et al., 1991; McCormick and Hennessy, 2002). “The processes involved in designing are not linear, they do not always start from human needs, and they do not always proceed in an orderly way. They are reiterative, spiralling back on themselves, proceeding by incremental change and occasional flashes of insight” (Baynes, 1992, pp.1). Even further, Kelly highlights how making students jump through problem-solving "hoops" unnecessarily can hinder their learning process (Kelly et al., 1987). Kelly and Johnsey advocate for using problem-solving techniques as guiding intentions towards an "evolutionary relationship" grounded in the students’ activity rather than used as discrete stages (Kelly et al., 1987; Johnsey, 1995).

The same stance is taken by Moshe Barak, who positions designed-based learning as project-based activities which require learners to work according to engineering design processes (Barak, 2020). Rather than a neat sequential procedure, Barak defines engineering design as "generating alternative solutions and choosing systematically the optimal one, because engineering is merely a process of optimization and tradeoff" (Barak, 2020, pp.94).

In the same vein, Mawson proposes that models of the design process employed currently in the teaching of technology in schools are fundamentally flawed, with a continued detrimental impact on children’s engagement with technology, and he calls for a rethink of the traditional frameworks for framing the design process (Mawson, 2003). He builds on Johnsey’s criticism of current design models being surprisingly similar to each other, portraying a linear progression poorly grounded in the reality of students’ actions (Johnsey, 1995; Mawson, 2003). Whilst these models provided security and guidance for non-specialist primary teachers, representing the children’s design in such simplistic terms led to negative effects on technology education learning objectives (Chidgey, 1994; Mawson, 2003). Exploring the design practices of both professional designers and children in existing literature (Barlex and Welch, 2009; Hill and Anning, 2001b), Mawson concludes that neither students nor experts use a predetermined process, instead repeatedly inventing a process as they advance in their tasks, informed empirically by their progress. Mawson stressed that the solution to a problem involves more variables than previously mapped in traditional frameworks, which cannot be lined up as a sequence of sequential steps (Williams et al., 2000; Mawson, 2003).

Baynes shows that young children enter school already able to design and construct, based on earlier experiences (Baynes, 1992). He argues that to engage students more effectively in design thinking, we need to learn more about how they naturally approach design problems, informed by their previous experiences. He advocates starting with authentic observations of children's actions as they engage in construction activities, rather than potentially misleading theoretical models, in a bid to arm teachers with a stronger foundation on how to build on children's existing skills and enhance their design practices through guided reflection on the students' activities (Baynes, 1992; Johnsey, 1995).

2.4.3 Iterative Design Process

The iterative design learning objective is a consequence of students engaging in Design-Based Learning (Barak, 2020). Brennan and Resnick define the iterative design as the cycle of prototyping, testing, and revision, that requires students to engage in a continually "adaptive process," throughout the course of creating a computational artefact, where one's goals "might change in response to approaching a solution in small steps" (Brennan and Resnick, 2012, pp.7). Iterative design is also a key practice highlighted in new secondary school computer science curricula, which reinforces the importance of iterative software development as "essential knowledge" (Fields, Lui, and Kafai, 2019).

Iterative design is a process of converting an ill-structured problem into a clearly-structured solution, a process which is not visible from a final artefact (Brennan and Resnick, 2012). Instead, iterations might be observed as a function of the number, types and patterns of transition behaviours, such as time utilisation, forward and backward cycles or the number of changes. The iterations form a sequence of transition behaviours, progressing towards a solution through different levels of abstraction (Adams and Atman, 1999).

As an activity, iterating can be a goal-directed, non-linear process that utilizes heuristic reasoning processes and strategies. These processes take place as designers attempt to gather and filter information about a design problem, and result in the revision, improvement or modification of possible solutions. Although the utilization of a cyclic iterative design procedure is believed to increase the efficiency of the process and lead to better quality solutions, there is little research that assesses iterative behaviours in terms of design competencies (Adams and Atman, 1999).

Fields et al. highlight further the importance of iterative practices for engineering, involving trial-and-error processes alongside revisions and refinements of ideas over time (Barr and Stephenson, 2011; Lee et al., 2011. The process of iterations and revisions are structured within the steps of the engineering design process: prototyping, testing and redesign (Tayal, 2013). The authors observe the students' iterations through the changes the students make in their projects, such as improvements to their circuit diagrams, changes in the code or alterations to the physical artefacts (Fields, Lui, and Kafai, 2019).

Promoting the Iterative Design Process

In their study, Fields et al. analyse the ways in which teachers promoted iterative thinking and design practices within their personalised electronic textiles projects (Fields, Lui, and Kafai, 2019). This occurred within predetermined constraints under which the students needed to create their projects. The teachers encouraged personalisation by allowing students to bring their own personal objects for modification, as well as customise the functionality based on their interests. The authors conclude that by encouraging personalisation within given constraints, teachers inherently guide students through an iterative process (Fields, Lui, and Kafai, 2019). This wasn't observed only within the remit of the students' work, but the teachers' work as well. Going through the same creative process encouraged teachers to reflect on their own processes, including their own experiences of trial-and-error, mistakes and iterations, and share these with their students. The authors describe a design process where students felt ownership over their creations, dealing with unique challenges and feeling motivated to persevere through mistakes and bugs (Fields, Lui, and Kafai, 2019). The design process is positioned as troubleshooting by isolating specific problems and iteratively trying out potential causes and solutions. Here, the personalisation aspect of the electronic textile activities is seen as the direct promoter of opportunities to engage in an iterative design process (Fields, Lui, and Kafai, 2019; Kafai and Burke, 2014). The study underlines the importance of designing learning experiences where there is an intentional awareness and acknowledgement of the importance of the iterative design process in solving design problems (Fields, Lui, and Kafai, 2019).

Three teaching practices are highlighted to promote a "classroom culture of iteration" (Fields, Lui, and Kafai, 2017; Fields, Lui, and Kafai, 2019). First, teachers showcase their own mistakes as a way to show the value of "process over product" (Fields, Kafai, and Searle, 2012; Fields, Lui, and Kafai, 2019; Kafai and Burke, 2014). Teachers highlight their own moments of failure and the resulting iterations which emerged, showing students that rarely a solution works the first time around, and encouraging them to prioritise persevering through various attempts over a search for a perfect first-time result. Second, teachers encourage a process of reflection, as a means to improve their techniques by analysing their own historical projects. Going past simply encouraging an iterative activity, the teachers get students to explicitly describe the way in which the iterative design process contributed to the emergence of their past solutions. Third, teachers build their own projects alongside students to enhance their supporting role, help them better understand what students are going through and more effectively share in the students' process. Through these three mechanisms, the authors argue that the teachers validate "process" over "product" for their students by enabling a "classroom culture of design" (Fields, Lui, and Kafai, 2019).

More generally, Smith et al. intricately link action and reflection in their design thinking model (Smith, Iversen, and Hjorth, 2015). In their model, based on observations of students' orientation towards technologies rather than steps in a process, they introduce a retrospective thinking tool to encourage students to think about "what ideas and what thoughts might have guided the designer to create a product with these qualities" at different points throughout the digital fabrication activities. They position failure, iterations and continuous reflection on the design process as core elements of design thinking which students can use to navigate "wicked" problems (Smith, Iversen, and Hjorth, 2015, pp.24).

Documenting the Iterative Design Process

A concrete means which enables teachers to further enhance an iterative design process, and support its design, reflection and understanding is to document it (Fields, Lui, and Kafai, 2019; Kafai and Burke, 2014; Brennan and Resnick, 2012).

Tseng et al. detail the methods by which documentation is produced and used in online DIY communities (Tseng and Resnick, 2014). They identify that for most designers, documenting and building are two distinct and often conflicting activities. Some participants from the study talked about the inconvenience of being interrupted in the building process by the need to document intermediate stages, and documentation is often forgotten about altogether. Another distinction was made between the actual construction designers go through, and documenting the most efficient route for others to recreate the same project, rather than evidence of the process. For those who viewed it as an effective route to reconstruction, they considered the documentation almost an entirely separate process where they take out any mistakes, ignoring all the ways in which they themselves could not achieve a result, and provide an almost "perfect" route to the output, thus not reflective of their own journey. Finally, some designers considered documentation a means of telling their stories, showing the realities of the whole construction process, including changes and mistakes. They felt this helped "demystify" the design process, however they also acknowledge the potential of damaging their reputation in the community when revealing the mistakes in the first place (Tseng and Resnick, 2014). From the perspective of designers looking for prospective projects to recreate however, there is evidence that they appreciate the in-progress explanations, even where these do not contribute to the end result (Tseng and Resnick, 2014). More than exact steps to identical replication, readers look at existing projects to customise and personalise. Therefore, understanding the pros and cons of specific methods or techniques is more helpful in applying them to their own projects than the fewest steps required to recreate identical replicas (Tseng and Resnick, 2014).

Portfolios, or digital journals, are often used in classrooms in project-based learning contexts as ways to track students' progress (Barak and Doppelt, 2000; Lui et al., 2018; Fields, Shaw, and Kafai, 2018). Specifically, teachers are increasingly looking for ways of documenting the students' journeys as they go through their construction projects, as a way of gaining insight into their thinking process which led to their final result, rather than relying solely on an end product to evaluate. Barak and Doppelt position portfolios as records of a pupil's learning process: a trace of what a student has learnt and how. As they document their process in the portfolios, the students' reflect on their own learning process as well as make their thinking more visible to the teacher and their peers (Barak and Doppelt, 2000). Lui et al. also discuss recent efforts to encourage students to report and reflect on their e-textile fabrication processes by documenting them in digital portfolios (Lui et al., 2018; Fields, Shaw, and Kafai, 2018). The documentation includes pictures of prototypes, mistakes, revisions or incomplete work. Research suggests that such documentation adds a formal element of analysing and supporting the iterative design approach which teachers already implement in their classrooms (Lui et al., 2018).

Using portfolios, evaluation is opened as a cooperative process between the student, the teacher and their peers. Teachers make their assessments based on the student's process and not just their final product. They allow for both self-assessment and peer-assessment to take place and allocate a final grade in collaboration with the student according to agreed marking criteria. Students are encouraged to include not only work in progress drafts of their artefacts, but also comment on the thinking process which led to the design decisions made along the way (Barak and Doppelt, 2000). Whilst these types of records hold great potential for a more holistic evaluation of robotic projects, Barak and Doppelt also document the students' reluctance to continuously track their work in progress (Barak and Doppelt, 2000).

Evaluating the Iterative Design Process

Approaches such as performance assessment, open-ended problems, interviews, journaling, portfolios, exhibitions, oral presentations and peer evaluations have emerged in an attempt to better align what is being assessed with the goals of "learning through designing" (Brennan and Resnick, 2012; Resnick and Silverman, 2005). These approaches are aimed at developing students' subject knowledge, as well as metacognitive and interpersonal skills (Gredler, 1995; Barak and Doppelt, 2000). Barak and Doppelt identify the necessary characteristics of constructivist assessment methods that align with its educational objectives: assessment is an integral component of the teaching and learning on-going process rather than a final stage; it focuses on the learning process rather than solely the end product; it characterises thinking and understanding rather than memory and rehearsal and it acknowledges the social and collaborative aspect of learning (Barak and Doppelt, 2000). An important aspect of constructivist-aligned assessment methods is the students' reflection on their own learning process (Barak and Doppelt, 2000; Gredler, 1995; Fields, Shaw, and Kafai, 2018).

Iterative design behaviours have most frequently been evaluated as part of wider Computational Thinking and Engineering Problem-Solving frameworks (Brennan and Resnick, 2012; Grover and Pea, 2013; Wing, 2006). Kong summarises proposed evaluation components of Computational Thinking across a variety of studies, which include "being iterative and incremental" as a distinct learning objective: (1) problem formulating, (2) problem decomposition, (3) abstracting and modularising, (4) algorithmic thinking, (5) reusing and remixing, (6) being iterative and incremental and (7) testing and debugging (Kong, 2019).

In their analysis of CT evaluation, Zhong et al. draw three main conclusions concerning the assessment of Computational Thinking competencies (Zhong et al., 2016). First, highlighting errors and integrating them into the learning process lead to effective ways of assessing CT. Second, semi-finished projects contribute greatly to the teachers' abilities to assess CT, in combination with the final end-product. Third, summative task evaluations are insufficient for accurately evaluating CT, and that process evaluation is needed to complement the students' abilities (Zhong et al., 2016).

Based on the three assessment strategies designed by Brennan et al., the authors recommend a holistic evaluation with a focus on process rather than final versions of the projects, through real-time comments, project notes, presentations and video descriptions of designs (Brennan and Resnick, 2012). This entails any form of encouraging students to think about their own design process, checking in at multiple points during the project, and moving beyond assessment solely from the researchers' viewpoint, with insights from teachers, students, peers or even parents and siblings (Brennan and Resnick, 2012).

Teacher inquiry activities in design tasks have traditionally depended on qualitative methods of reflection, however interest in the use of student data as evidence to inform this process has been increasing (Wasson, Hanson, and Mor, 2016). In a large-scale study of university students design problem-solving behaviour, it was found that Year 1 students had fewer transitions between designs steps and a lower number of transitions per minute compared to more senior students, and that transition behaviour for both groups of students related positively to the quality of the final design (Adams and Atman, 1999). Also, seniors were found to exhibit more problem scoping behaviours, and the number of constraints considered correlated with the quality and number of alternative solutions generated. Radcliffe and Lee found that the adoption of a systematic, iterative and logical design sequence correlated with the effectiveness of the design and the efficiency of the designer's process (Radcliffe and Lee, 1989). Learning analytics could support the iterative design reflective cycle with detailed evidence of the students' actions and investigating the impact of teaching decisions on learning (Mor, Ferguson, and Wasson, 2015). Temporal data analysis which captures time-based characteristics of trace data yields exciting opportunities "to move towards a new paradigm of assessment that replaces current point-in-time evaluations of learning states with dynamic evaluations of learning progress" (Molenaar and Wise, 2016). However, despite the potential of learning analytics research to use the data emerging from the use of physical computing kits to better account for the iterative design process student engage in, such research is yet to emerge.

So far in this chapter, the educational theory and pedagogical implications of students engaging in open-ended practical design tasks using physical computing kits was explored. Next, the potential Learning Analytics has towards improving the analysis and support of such contexts is presented in detail. State-of-the-art research in similar contexts is presented alongside challenges and gaps.

2.5 Learning Analytics in Open-Ended Learning Contexts

The analysis of digital traces generated from students' learning activities is the focus of the learning analytics research community, defined as "measurement, collection, analysis and reporting of data about learners and their contexts, for purposes of understanding and optimizing learning and the environments in which it occurs" (citesiemens2012, pp.1).

Blikstein and Worsley articulate the potential of learning analytics to study open-ended learning tasks in contexts where students build personalised designs using robots and computer programs (Blikstein and Worsley, 2016).

In their study, Blikstein and Worsley exemplify the power of capturing multimodal interactions using trace data, wearable cameras, sensors, gestures and eye-tracking to gain insight into the multiple dimensions which unfold in complex learning tasks (Blikstein and Worsley, 2016). Examples include natural language processing of open-ended writing tasks which allows drawing commonalities and differences among a large population of students (Sherin, 2013), speech analysis to predict students' level of expertise in open-ended engineering design tasks (Worsley and Blikstein, 2011) or action and gesture analysis to estimate the students' level of attention (Raca, Tormey, and Dillenbourg, 2014).

In terms of processing data from open-ended learning environments, Kinnebrew et al. have developed adaptive scaffolding methods which track and interpret students' learning activity (Kinnebrew, Segedy, and Biswas, 2017; Leelawong and Biswas, 2008). They highlight the challenges of studying open-ended learning environments, which require students to make choices on how to structure different solutions, explore alternative answers, and develop increasingly effective strategies to solve the tasks. They focus on students' self-regulating capabilities to regulate their learning and develop an awareness of their problem-solving skills (Kinnebrew, Segedy, and Biswas, 2017). They integrate a model and data-driven techniques to characterise students' learning behaviour. Through their analysis, they show that different students may employ similar patterns of action, but in different ways, and for different purposes (Kinnebrew, Segedy, and Biswas, 2017). In this way, they seek to better understand how learning happens in open-ended contexts rather than purely generating opaque student models, which might aid predictions, but stop short of explaining those predictions in ways that can be supported.

Finally, a comprehensive evaluation of outcomes modelled using LA techniques from open-ended exploratory learning environments was conducted by Fratamico et. al, using a combination of classification, clustering, mapping and predictive algorithms (Fratamico et al., 2017). The authors used a theoretical framework to group students based on their learning achievements, they employed different amounts of granularity and feature engineering to evaluate the accuracy of alternative representations of logged interaction data (Fratamico et al., 2017). The students' interaction behaviours were modelled according to the theoretical framework and mapped into learning outcomes as a predictive model for new learners. The success of the prediction allowed the authors to compare the validity of different representations, with valuable findings around what level of granularity is needed when deciding what data to feed the system and to what degree feature engineering of various interactions can be helpful. In addition, they identified patterns of interaction extracted from association rules correlated to low or high learners which, they found, were conducive to a more or less effective exploratory learning experience (Fratamico et al., 2017). These were mostly specific to the engineering task undertaken, but more general trends such as low learners displaying infrequent pausing, pointing to a lack of adequate reflection, were also observed (Fratamico et al., 2017). Blickstein and Worsley used machine learning on hand coded video data to identify general patterns in engineering design, open-ended, hands-on tasks (Worsley and Blikstein, 2014). In their study they seek to develop a "fine-grained representation of how experience relates to engineering practice" (Worsley and Blikstein, 2014, pp.1). They looked at iterative design practices, the link between trial and error practices and the emergence of sound engineering principles, and they showed that the students' level of experience is closely correlated to both the intent and context of engineering practices (Worsley and Blikstein, 2014).

The studies presented in this section offer a short review of the ways in which Learning Analytics is positioned to support open-ended learning environments across multiple aspects: modality of data as input for LA systems, methodologies of processing LA data as well as outcomes modelled with LA. Next, the challenges in undertaking LA research in open-ended learning environments, as well as directions for addressing current research gaps are presented.

The studies mentioned above are highlighted as exceptions among most of the learning analytics research which focusses on higher-education online course contexts, which offer a high degree of structure of the learning journey as well as being limited to virtual on-screen interactions (Blikstein and Worsley, 2016). In contrast, student-centred exploration of open-ended design tasks has been less studied, both due to pedagogical challenges of implementing constructivist-inspired methodologies in the classroom, as well as the complexities of studying these using data (Blikstein and Worsley, 2016). The authors point to the dangers of using data predominantly in "direct instruction" contexts, where standardised measures and frameworks make it easier to quantify and analyse the set learning objectives.

Learning analytics could deepen the asymmetry between the two educational approaches, therefore help lead to the elimination of one in favour of the other. Questioning the goals of the educational contexts helps position learning analytics tools as support for the most meaningful learning objectives, rather than those easiest to quantify help ensure analytics methods (Worsley and Blikstein, 2011). The authors advocate for developing new methods for the examination of non-standardised forms of learning that place emphasis on student-centred, constructivist, self-motivated learning which demand higher-level, complex problem-solving skills, where students create unique paths to personalised solutions, interact heavily with peers and interact in hybrid physical and digital contexts (Worsley and Blikstein, 2011).

In addition, the studies cited above signify important progress in evaluating exploratory learning activities in more automated ways, and therefore advancing a more sophisticated understanding of students' learning. However, many current studies are still experimental laboratory-based studies where the data collection and tracking can take place in controlled environments, over relatively short periods of time, rather than observation of patterns in the real world.

Finally, almost all studies correlate back to a final assessment of an end result, even when trying to identify patterns in students' behaviours in the process of creating their designs. A recent literature review conducted on the role of temporal aspects of teaching and learning found that time played almost no role as a variable in education technology research (Barbera, Gros, and Kirschner, 2015). Automating feedback and progress predictions based solely on outcomes can have detrimental consequences, in a similar way that teaching to test has negative effects versus teaching to improve understanding (Gašević, Dawson, and Siemens, 2015). Whilst end-products are good proxies for showcasing the work invested in the final outcome, they tell us little about what was left out, which forms an important part of the learning process. In addition, assessments based solely on final outputs offer little insight into the specific ways in which we can support and better design the projects in the making, as they unfold. The challenge with analysing cognitive behaviours is that they occur as a process, in context. They are fluid, multi-dimensional aspects of learning (Duckworth and Yeager, 2015).

Ferguson identifies two main challenges when it comes to designing effective learning analytics: 1) building strong connections to learning sciences and 2) focusing on the perspective of learners (Ferguson, 2012). In their study, Gasevic, Dawson and Siemens draw attention to the need for learning analytics to be built on and connected with existing research on learning (Gašević, Dawson, and Siemens, 2015). Furthermore, learning analytics developments should draw on and advance educational research and practice (Gašević, Dawson, and Siemens, 2015). A critical social-technical perspective on learning analytics posits that: 1) learning analytics need to reflect the students' lived reality, offering open and accessible analysis that offers genuine control and oversight to users; 2) there are growing concerns around the lack of nuance in learning analytics systems that reflect the social complexity of classroom activity; 3) an over-reliance on learning analytics reduces students' and teachers' capacity for informed decision-making by directing or determining their decision-making, which not only undermines professional judgement and expertise, but runs the risk of entrenching old, inaccurate status-quos (Selwyn, 2019).

2.5.1 Process-driven Learning Analytics

In contrast to automated performance predictions using different forms of summative feedback, some learning analytics researchers focus instead on the "continual and real-time assessment on student process and progress, in which the amount of formative feedback is radically increased" (Berland, Baker, and Blikstein, 2014, pp.208). Paying attention to teaching and learning processes whilst prioritising the instructional and sensemaking benefits for learning can avoid the very limitations current evaluation methods pose, that the learning analytics community now aims to overcome. Underpinning the focus on process and temporality is the understanding that learning is a continuous, dynamic process that evolves over time (Kapur, 2011b).

An increasing number of researchers have highlighted the need to pay increased attention to time in the learning process (Kapur, Voiklis, and Kinzer, 2008; Wise et al., 2012). Analysing the temporal characteristics of pedagogical constructs can enhance the explanatory power of what is presented in the data (Molenaar, 2014).

Two examples of studies which focus on temporality in the domain of computer-supported collaborative learning are Kapur and Mutlu (Kapur, 2011b; Kent and Cukurova, 2020). These studies unpack temporal patterns in group interactions and lead to a greater understanding of how collaborative problem-solving evolves over time and relates to group and individual performance (Kapur, 2011b; Kent and Cukurova, 2020). These methods stand in contrast with traditional analytics approaches, which for the most part present cumulative accounts of student interactions and correlate them to single points of assessment (Kapur, 2011b; Kent and Cukurova, 2020).

Emerging methods such as Markov Modeling (Segedy, Kinnebrew, and Biswas, 2012), temporal pattern analysis (Magnusson, 2000), sequential log analysis (Bakeman and Gottman, 1997) and data visualizations (Reimann, 2009) have been used to add time analysis into the data-driven exploration of learning processes.

The emphasis on temporality in learning analytics leads towards establishing success criteria which characterise learning as a continuous process, rather than snapshots in time. To achieve this, an understanding of the temporal characteristics that indicate learning needs to be achieved, which includes important questions over what characteristics should be measured, how these unfold over time, and the best tools which might help us achieve a meaningful real-time exploration of learning in classrooms (Molenaar and Wise, 2016). Molenaar outlines with clarity the challenges of analysing learning constructs, such as self-regulation, as a series of events unfolding over time (Molenaar, 2014).

Reimann also advocates for the inclusion of temporality into the study of learning constructs by making full use of information with respect to time and order. He positions this against the predominant approach in learning analytics, the variable-centred variance theory (Reimann, 2009), which he argues is of limited value when applied to social sciences such as learning, which unfold over long periods of time. He proposes an event-centred view of process as a way of more closely linking quantitative and qualitative approaches, with events as the basic unit of analysis (Reimann, 2009).

Using events as the unit of analysis re-directs traditional grade-based assessments to time-based properties of the learning process (Kuvalja, Verma, and Whitebread, 2014) or sequence of actions (Molenaar and Wise, 2016). In contrast with variable-based analysis at static points in time, events-based approaches look at analysing the dynamic nature of learning constructs and how these unfold over time (Molenaar and Wise, 2016). This includes analysing individual time-related characteristics within a continuous flow of activity. For example, studies have found that planning at the start of a learning task is more productive than planning later on (Moos and Azevedo, 2008).

As well as investigating reoccurring processes such as the cyclical notion of self-regulation, time-based analysis can also be used to explore irregular activity. For example, the concept of productive failure in the context of collaborative problem-solving shows that initial chaotic, divergent and possibly underperforming short-term collaboration efforts lead to subsequently improved performance on both well- and ill-structured problems (Kapur, 2011a). Students solving complex problems in small groups without any instructional facilitation, despite failing in their immediate tasks, performed better on subsequent well-structured problems, as well as demonstrating greater representation flexibility when working with graphical representations (Kapur, 2011a).

In their study, Molenaar, Horvers and Baker build moment-by-moment learning curves to explore primary school students' self-regulated learning when using adaptive learning technologies in maths education (Molenaar, Horvers, and Baker, 2021). They develop personalised visualisations for learners which show how much the learner is likely to have learnt at each problem-opportunity as a representation of learning over time. They found that moment-by-moment learning curve indicators are related to learning outcomes, meaning that such curves can offer insights into the students' learning from on-going real-time data collection rather than isolated tests. They conclude that moment-by-moment learning curves, distilled automatically from students' data traces, visualize student progress in learning over time, which can be used to think about the role that effort plays in learning progress (Molenaar, Horvers, and Baker, 2021).

Trace data has been shown to support temporal characteristics of students' learning strategies during well- and ill-structured tasks (Malmberg, Järvelä, and Kirschner, 2014). Trace data can be used to overcome the issues self-reporting presents, such as student over or under-estimating their own performance or think aloud procedures interrupting their natural trail of actions (Malmberg, Järvelä, and Kirschner, 2014).

A significant challenge in many learning analytics studies is the gap between the granularity of temporal data collected at a micro level, and the theory defined at a macro level(Molenaar, 2014). In contrast to the "death of theory" proclaimed by some as a consequence of the "big data revolution" (Wise and Shaffer, 2015; Mazzocchi, 2015) argue that especially in the case of large datasets where spurious statistically significant patterns can be easily obtained, theory is important to guide interpretation (Wise and Shaffer, 2015). To ensure the validity of data segmentation into meaningful constructs related to theory, researchers have combined different methodological approaches, such as ethnography and data mining, to make connections between the micro and macro levels (Azevedo, 2014; Shaffer, 2017; Bannert, Reimann, and Sonnenberg, 2014; Molenaar and Järvelä, 2014). The quest of connecting the micro and macro levels is often referred to as mapping “from clicks to constructs”, which entails approaches to analysing low-level log data to generate proxies for higher order constructs that educators and students can understand (Wise and Shaffer, 2015; Shaffer, 2017; Shute and Ventura, 2013). Whilst some work has been done on "giving meaning to data" (Echeverria, Martinez-Maldonado, and Buckingham Shum, 2019), more research is needed to map low level data collected in project-based environments to meaningful data proxies which reflect the complexity and nature of open-ended hands-on learning activities (Blikstein and Worsley, 2016; Berland, Baker, and Blikstein, 2014). This research builds on the quantitative ethnography approach pioneered by Shaffer (Shaffer, 2017) to address the challenge of moving from high level theoretical constructs to low level data and take a process-driven approach to match the nature of the learning context to the data exploration.

2.6 Data Visualisations

2.6.1 Data Visualisations Definition

The learning analytics community positions in clear contrast the intelligent systems which seek to automate decisions, against tools which attempt to enhance the decision-making capabilities of teachers and students. Visual analytic systems (Bederson and Shneiderman, 2003) are one such supporting tool, aimed at empowering decision-makers with increased evidence that is displayed in intuitive ways (Lang et al., 2017). The argument brought forth favours using data to support the decision-making process with additional information rather than replacing it, thereby contributing to the pedagogical goal of enhancing 21-st century skills such as collaboration, communication, critical thinking and creativity (Lang et al., 2017).

The terms of data visualisations, "information visualisations", "visual representations" and "dashboards" are often interchanged as synonyms in the learning analytics literature. Broadly, they are defined as instruments which ”capture and visualise traces of learning activities, to promote awareness, reflection, and sense-making, and to enable learners to define goals and track process towards these goals” (Verbert et al., 2014, pp.1499). The predominant goal of data visualisations is to bring awareness of the learning process and enable discussion between teacher and students, based on the information provided (Lang et al., 2017).

Information visualisation usually concerns the representation of abstract data in models which can be used to amplify cognition (Card, 1999). Often, models are built to allow humans to discover patterns or trends in the data, making use of our powerful perceptual abilities. Building visual model representations for human interpretation often leads to more precise and revealing results than the use of traditional statistics (Tufte, 1985). However, in order to achieve this, data collection strategies are required that ensure the integrity of the model, as well as methodologies for ensuring the accuracy of what is being visualised.

For example, Echevarria et al. contribute to the enrichment of data streams with qualitative insights, positioning these as necessary to make sense of quantitative information (Echeverria, Martinez-Maldonado, and Buckingham Shum, 2019). Echevarria's study aims to bridge the gap between students' interaction logs and higher order learning constructs (Echeverria, Martinez-Maldonado, and Buckingham Shum, 2019; Milligan and Griffin, 2016; Shute and Ventura, 2013) in hybrid contexts.

Data visualisations aimed at helping teachers visualise their students' performance also recognise how the teachers' idiosyncrasies influence the interpretation of the information offered. One study has identified that when interpreting the information in dashboards, teachers drawn on their additional knowledge of the individual student or the class to decide on whether and how to intervene (Molenaar and Campen, 2018).

2.6.2 Process Data Visualisations

Yan et al. have researched visual ways of helping in the assessment of first-time programming by computer science undergraduate students. The authors have developed a visual way of representing students' progress, using techniques from computer vision to characterise all the intermediate images of students' programs (Yan, McKeown, and Piech, 2019). The tool called Pensieve is aimed at facilitating student-teacher conversations about the programming process. In a further study, they stop short of interpreting students' coding outputs, and simply offer a simple visual tool that organises snapshots of students' code as they progress through the assignment (Yan, Hu, and Piech, 2019). Results indicate increased metacognitive and programming skills in the students using the tool. The design of Pensieve is based on the fundamental understanding that feedback is not a one-sided, teacher-led conversation, but a student-teacher balancing act between students' thinking processes and teachers' learning objectives (Yan, Hu, and Piech, 2019; Yan, McKeown, and Piech, 2019).

Similar principles are applied in the design of the Replay tool, a self-documenting construction kit, where students can share both their designs as well as the way in which these were constructed (Tseng, Hemsley, and Resnick, 2012). The design intends to overcome the challenge of reconstructing a model to be shared with others, not only as a final design, but also the construction process, creating opportunities to reflect on design strategies. The kit generates a visual model of the physical design, which can be viewed through a software interface that shows how the design was built, generating an instruction-guide-like sequence of reconstruction steps (Tseng, Hemsley, and Resnick, 2012). The authors' goals are to allow students to share their creations with each other, create opportunities for remixing others' designs, learning from each other and reflecting on their design processes (Tseng, Hemsley, and Resnick, 2012).

A further example of emphasising the visualisation of a process is offered by Ben Fry's "The Preservation of Favoured Traces" (Fry, 2009; Fry, 2008). His representation explores static and interactive ways of showing the evolution of a text, using Charles Darwin's "On the Origin of Species" as an example (Fry, 2009). The visualisation is shown in Figure 2.1, with the interactive version available at `https://benfry.com/traces/`. It is a visual demonstration of how scientific theories are adapted and developed over time before their widespread adoption. Ben Fry highlights the revisions Charles Darwin made to the book since its original publication in 1859 across six editions. The tracked changes show that the concept of the "survival of the fittest" wasn't introduced until the fifth edition (Fry, 2009).

The visualisation represents a story of the edits of Darwin's thoughts on

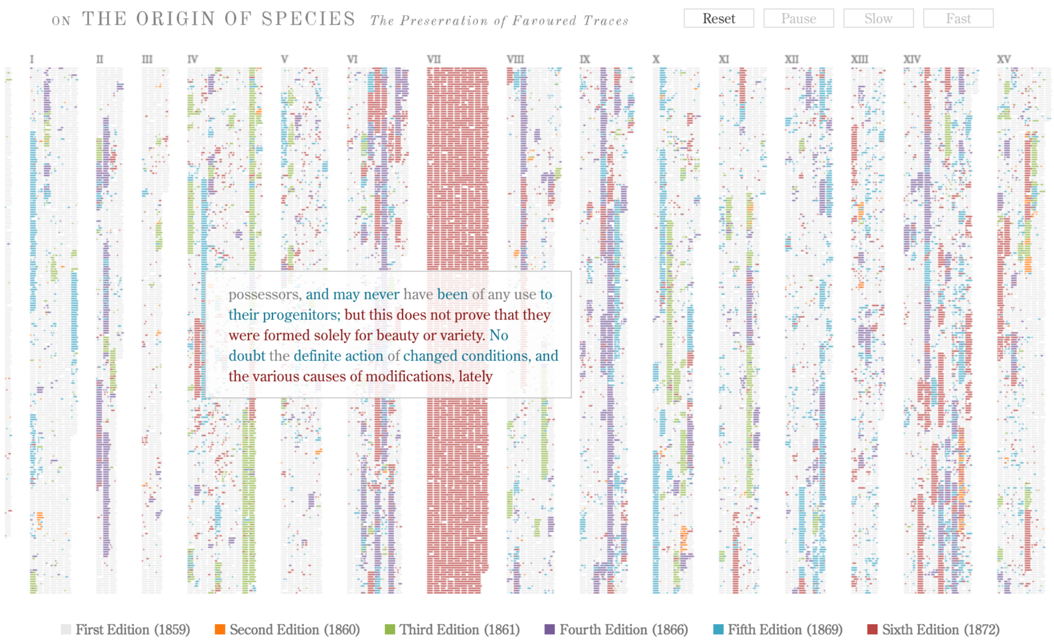


FIGURE 2.1: The Preservation of Favoured Traces, Ben Fry

evolution, shifting the focus from his final output to the way in which he built on each version to evolve his theories, before being as widely accepted as they are now. One can imagine, had he survived longer, this process would have continued, and the sixth version would have remained just one of the steppingstones towards new insights.

These studies provide concrete examples of the ways in which events, such as changes between consecutive iterations, can constitute a unit of analysis for documenting and visualising the students' construction process. In addition, they offer perspectives on the definition of teacher scaffolding in similar contexts as well as using visual representations of progress to serve as reflection tools.

Data visualisation research work has been concentrated on exploring digital traces of online learning experiences to make interactions visible and infer patterns of behaviour (Martinez-Maldonado et al., 2019). However, research repeatedly shows the lack of connection between learning analytics dashboards and learning sciences (Jivet et al., 2017). In addition, much more needs to be done to connect the time-based process-oriented learning analytics research with the possibilities data visualisations offer to provide evidence-based insights to guide the learning process. Furthermore, the specific link between leveraging the educational support role of data visualisation and the need to inform students' iterative design process in contexts where students learning using physical computing kits is yet to be explored.

2.7 Summary

Learning analytics offers a unique opportunity to advance our understanding of iterative design work towards a more realistic picture of what students engage in, grounded in their actions, and informed by theory. So far, learning analytics research in project-based learning contexts using physical computing kits remains ephemeral, due to classroom complexities and discrepancies between traditional design and evaluation paradigms and emerging constructivist approaches. However, emerging research shows how data capturing students' actions could help support students in open-ended, hands-on learning using theory-informed, context-aligned models to represent activity. Yet, little learning analytics research has focused on the iterative design process as a learning objective. Even more, no studies could be found that explore the potential of visually representing the iterative design process, with the purpose of characterising and supporting aspects of students' iterative behaviours.

Figure 2.2 summarises how the existing research and gaps presented in this chapter motivate the wider research context and inform the main research questions, as an extension of Figure 1.1.

The first question "How can trace data be used to visualise the evolution of students' SAM Labs designs?" addresses the lack of theory-informed quantitative proxies to represent the iterative design process from authentic learning contexts, which emphasise the characteristics of the learning context and its objectives. The importance of students formulating their own construction goals, as this emerges from appropriation literature in open-ended learning tasks, is accounted for in the formulation of visual proxies of the students' iterative behaviours. Furthermore, we build on research which positions learning as a continuous, evolving process rather than divided into discrete stages (Johnsey, 1995), considering the "process as a product" (Fields, Lui, and Kafai, 2019), using the students' work in progress recorded in the trace data.

The second question "How can visual representations of students' evolving designs be used to characterise the iterative design process?" addresses the issue of limited concrete attributes available to interpret the students'

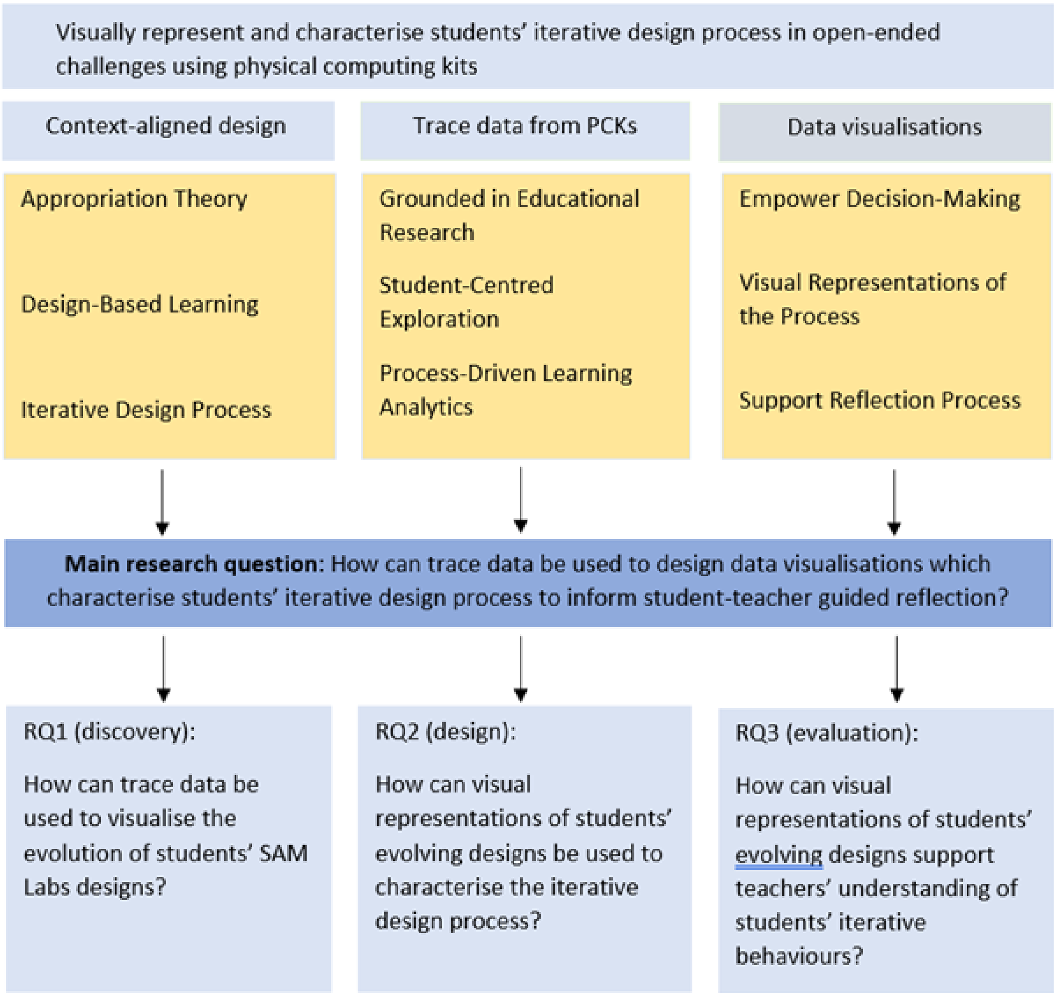


FIGURE 2.2: Summary of existing research and research questions

iterative design activity. Trace data is used to characterise the iterative design process, recognised in the learning analytics research as attempting the bridge the gap "from clicks to constructs" (Shaffer, 2017).

Finally, the third research question "How can visual representations of students' evolving designs support teachers' understanding of students' iterative behaviours?" addresses the need for learning analytics tool to surface not only what users do, but also why. We build upon research highlighting the potential of data visualisations to increase visibility, awareness and accountability (Erickson and Kellogg, 2000; Liu and Nesbit, 2020) in the evaluation of the potential of our data visualisations to increase the efficacy of the student-teacher guided reflection process.

The thesis brings together different areas of educational and analytics research - learning with physical computing kits, appropriation theory, process-driven learning analytics and data visualisations – to drive the design and evaluation of data visualisations that aim to support the iterative design process in open-ended project-based learning activities using physical computing kits.

This chapter has laid out the existing research related to young people learning using physical computing kits, specifically in the context of design thinking, learning through designing and the iterative design process. Appropriation is presented as an inherent part of students engaging in open-ended construction projects using physical computing kits and learning through designing. Common ways of analysing and visualising data collected from such learning environments is presented, with gaps identified in the learning analytics literature. These gaps are correlated to the research question the present thesis is positioned to answer. In the following chapter, the learning contexts and methodology used to answer the research questions are presented. The SAM Labs physical computing kits are explained, and two learning contexts are detailed where the researcher observed and collected data from. The data collected and the ways in which the data was used to answer the research questions is outlined.

Chapter 3

Learning Contexts and Methodology

This chapter presents the learning contexts and methodology used to explore the research questions. The chapter comprises of four sections. The first section introduces the SAM Labs physical computing kit's makeup and functionality. The second section details the two main learning contexts in which the research is situated. The third section outlines the data collected to investigate the research questions. Finally, the fourth section presents the four stages of the research, following the Design-Based Research methodology structure. The discovery, design, evaluation and reflection research stages are explained in relation to the research goals.

3.1 SAM Labs physical computing kits

The Sam Labs computing kits are made up of blocks (or components) connected into electronic circuits via a virtual interface (SAMLabs, 2022). The two terms, blocks and components, are used interchangeably throughout the thesis, and they refer to the same thing: the individual pieces which are connected into electronic circuits and make up the functionality implemented through the SAM Labs circuits. The blocks are either physical, tangible pieces which are assembled in real life to make up a physical artefact, or virtual, used only in the virtual interface to influence the behaviour of the physical components throughout the circuit. The physical blocks connect to the virtual interface via Bluetooth. An example showing both the physical components and its virtual counterpart making up a car is given in Figure 3.1 below:

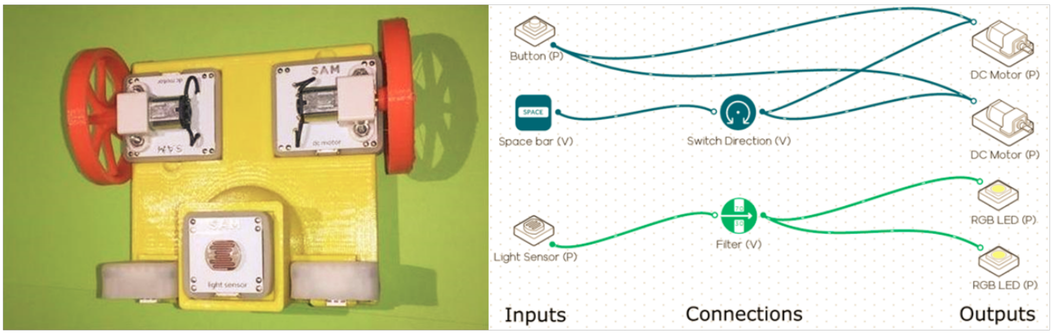


FIGURE 3.1: SAM Labs Components: Physical blocks (right) and virtual circuit (left)

The left-hand picture in Figure 3.1 shows a car constructed with 5 physical blocks: 2 DC Motors, 1 Button, 1 Light Sensor and 2 RGB Lights. The right-hand picture shows the virtual circuit with the 5 physical blocks labelled (P), and 3 virtual blocks labelled (V). The circuit is organised in three columns: inputs, connectors, and outputs. The columns signify the three roles SAM Labs blocks can play in a circuit:

- **Inputs** are the blocks that will trigger the circuit into action, either manually using buttons, keyboard keys, or automatically through sensors or timers. The car in Figure 3.1 uses 3 inputs, the button to power the car going forward, the space bar to get the car to move backwards, and a light sensor to turn on the car lights in the dark
- **Connectors** are virtual blocks which manipulate the behaviour of the output after being triggered from the input. Connectors are always positioned between the inputs and the outputs in the circuit. The examples in Figure 3.1 include a switch direction connector, which changes the direction in which the motors spin every time the space key is pressed, and a filter connector, which dictates the amount of light required for the light sensor to turn on the LEDs
- **Outputs** are either physical or virtual blocks which action the result of the circuit after being triggered from the input. In the car example, the outputs are the motors powering the wheels and the LED lights acting as headlights

The underlying principle governing SAM's functionality is the construction of input – connector – output circuits using blocks which can act on each other's instructions. The list of all SAM Labs components, their type and category is attached in the Appendix A. Edges represent the direct connections between any two blocks, with multiple blocks and edges connected making up a circuit. The combination of all circuits used in one project comprises a graph.

The SAM Labs kit is designed specifically with the purpose to be re-mixed in different contexts, for different behaviours (SAMLabs, 2022). Theoretically, any input can be connected to any output, and their behaviours can be enhanced by any available connector, provided the blocks are able to understand each other's commands. For example, a button can be connected to a custom code block, which can be programmed to contain a number randomiser function. If the custom code block is further connected to an LED, this will never turn on, because the LED block only understands On/Off commands, and cannot interpret a number resulting from the custom code block. The rules require some experimentation to understand the exact nature of input and output commands each block is able to interpret. In addition, the tool allows the flexibility for any connection to be made, thus allowing for circuits to be created in ways which were not envisaged by the designers, but fit the goals of the users. Users can remix the blocks according to the input-connector-output sequence, fundamental to the construction of SAM Labs circuits, in order to discover the type of instructions each block is able to understand and combine these in any way they see fit to achieve desired behaviours.

The SAM Labs kit lends itself to the study of iterative design process in relation to appropriation, by looking into the various ways in which students assemble the SAM blocks into different circuits, and continuously adapt them in relation to self-made goals. For example, within the project brief of building an alarm system during one of the code clubs, students find multiple ways of building it: adding a disco lighting setting to capture attention and reduce the aggravation the usual bright red light causes, adding timed warning sounds in waves rather than a continuous loud noise, building in different pitches for different hearing frequencies, or using vibrations for deaf and blind people.

TABLE 3.1: Key differences between learning contexts

SAM Labs Code Clubs	Intelligent Board Game
Low school familiarity with PCKs	High school familiarity with PCKs
Code Club Informal Learning	Formal Curriculum-aligned Learning
Six projects x 1 hour challenges	One project spanning two terms

3.2 Learning Contexts

The following section presents the two learning contexts within which the current research is situated. The purpose and implications of the two contexts for the research are further explored in the last section of this chapter, where they are positioned within the different stages of the design-based research approach. The present study is situated in two complementary learning contexts. First, a series of school visits and code clubs were organised and attended. The schools varied in terms of their experience of using SAM Labs code clubs, from schools with little to no experience of using physical computing kits, to schools with several years' experience of both SAM Labs and other computing tools. This initial investigation informed the second and principal research context, a long-term project consisting of 12 students engaging in building "intelligent" board games using the SAM Labs physical computing kits.

All children included in the research were in Year 7. Year 7 is the first year group in Key Stage 3 of compulsory UK education, generally aged 10 or 11. This age group is a primary target for the designers of the SAM Labs physical computing kits (SAMLabs, 2022).

The two learning contexts allowed the researcher to investigate the practical implications of using physical computing kits in learning both at a beginner and advanced level. Moreover, the distinct contexts exposed the researcher to the variety involved in designing learning experiences with physical computing kits. This allowed for a precise contextualisation of the design and evaluation of the data visualisations, informed by the diversity present in authentic settings. The two contexts are explained in detail below and the key differences are summarised in Table 3.1.

3.2.1 Context 1: SAM Labs Code Clubs

To better understand the practical implementation of the SAM Labs kit in authentic classrooms, six schools were observed in their use of SAM Labs kit across two different settings. Three of the schools had never used the SAM Labs kit and had very little to no experience with using any physical computing kits. These schools were approached with the proposal of a code club being organised by SAM Labs representatives in partnership with the researcher, over six weeks. The other three schools already had experience teaching with physical computing kits, including the SAM Labs kit. Here the researcher simply observed one of the lessons which included the use of SAM Labs kit, followed-up by informal teacher interviews. The two settings are separated in two sub-sections below.

SAM Labs Code Clubs

Below we present the details of the code clubs organised at the three schools who had never used the SAM Labs kit before and had very little experience of other computing tools. The code clubs were attended by one class of 12 – 15 students from each of the three schools. The code clubs ran for six weeks, once a week, each lasting one and a half hours. They were led by a representative of the SAM Labs team alongside the researcher. The code club activities were prepared by the SAM Labs representatives in partnership with the researcher, every session constituting a new challenge. The activities built on each other week-by-week, with new additional elements or changes brought in every week. The challenges were open-ended, within clearly formulated boundaries. Table 3.2 outlines all the code clubs organised part of Learning Context 1:

TABLE 3.2: SAM Labs Code Clubs

Date	School	Challenge Name
28/09/2017	School A	Reaction timer
29/09/2017	School B	Basic Car
03/10/2017	School C	Morse Code
05/10/2017	School A	Buggy Tag
06/10/2017	School B	Super Selfie
10/10/2017	School C	Alarm System
12/10/2017	School A	Car Racing Ground

31/10/2017	School C	Car All Directions
07/11/2017	School C	Car Racing Ground
09/11/2017	School A	Alarm System
10/11/2017	School B	Car Racing Ground
14/11/2017	School C	Buggy Tag
17/11/2017	School B	Morse Code
21/11/2017	School C	Super Selfie
23/11/2017	School A	Super Selfie
24/11/2017	School B	Buggy Tag
28/11/2017	School C	Smart House 1 - Fire Alarm
30/11/2017	School A	Smart House 2 - Santa is coming
01/12/2017	School B	Smart House 1 - Fire Alarm
15/12/2017	School B	Smart House 2 - Santa is coming

Each code club followed a similar structure. To start, the students would be introduced to the construction challenge and the functionality of relevant blocks which could be used to build it. Afterwards, they were tasked with designing their own artefact within specified boundaries of a target construction. Throughout the activity, students were supported in the construction of their chosen designs, using guiding questions or helpful tips.

For example, the Basic Car activity had to result in a wheel-powered moving artefact, using at least 2 DC Motors to power the wheels, and have the capability to move forward and backwards. The students were presented with the light sensors and LEDs which they could use to implement headlights in some form. Within the specified boundaries, the students were free to choose how they triggered their behaviours, either automatically using a sensor or manually using for example a button, as well as what connectors to use to manipulate either the motors or the lights. The car could be programmed to simply go forward and backwards or be enhanced to drive in multiple directions. The headlights could be triggered manually or based on the light sensor, and it could beam a constant light, flash in different colours, or permutations of the above. Both the constraints of each activity the students had to abide by, as well as their open-ended options were clearly laid out for the students at the beginning of each session. The "Lesson Plan Structure", after which all code club activities were designed by is attached in Appendix B.

Students worked on the activities in groups of either two or three, within the social context of their classroom where they could look at other groups' work, ask each other questions and comment on each other's constructions. The SAM Labs representatives supported the students by demonstrating the blocks' functionality in a few examples at the start of each code club, followed up by advice throughout the activities at points where students would get stuck. At the end of each code club, each group of students would present their work to their peers and discuss how and why they arrived at their final construction, as well as what changes they would make if they had more time.

The code clubs also aimed to introduce teachers to the SAM Labs kit, with the intention of leaving the physical blocks with the schools, to continue their usage after the end of the code club series. Therefore, the teachers were not only also present in the code clubs, but also took part in the artefact constructions, helped with the general classroom management, and participated in the support offered to students when needed. Despite the kits being new for the teachers as well, they were encouraged to work through the problems with the students.

Schools using SAM Labs

An additional three schools were visited where the SAM Labs kit had been used with students for at least one year. Within all three schools, the kits were used both for after-school code clubs, as well as integrated within school-time lessons, across several school years, starting in Year 4 and going up to Year 11.

Each school was visited once during a Year 7 lesson, at the teachers' suggestion of the most convenient lesson for the researcher to observe. The observed lessons were part of the formal school schedule rather than an after-school club, at the researcher's request. After the lesson, the teachers were engaged in an open-ended discussion about their use of SAM Labs in the classroom. The visits were conducted during the same period as the code clubs at the three schools who had not used the SAM Labs kit before.

The lessons were centred around specific computing curriculum concepts. Despite SAM Labs' design targeting cross-curricular activities, as well as self-reported desires from teachers to use the kits across multiple subjects, the kits were mostly used for computing lessons and coding clubs only, on their own or integrated with other computing tools. The teachers' goals and ways of using SAM Labs were formulated within existing frameworks such as the Maker-Centered Learning (MakerEd, 2022) or the International Baccalaureate MYP Design Cycle (IBMYP, 2022).

Further details on the purpose of the visits and their role in the research is presented in Section 3.4. The resulting observations and the ways in which they informed the next phase of the research are presented in Chapter 5.

3.2.2 Context 2: Intelligent Board Game

The principal learning context in which most of the research data was collected and analysed was the "intelligent board game" project, which took place at the Keble Preparatory Primary School. The Keble Preparatory School is a boys-only public school in North London, UK. Despite it being a fee-paying independent school, the teacher followed the computing curriculum with her students. The teacher who designed the project was one of the earliest adopters of the SAM Labs physical computing kits in the classroom. The teacher purchased the kits and used them primarily to combine the virtual computing lessons with physical programming, as a way of complementing the students' virtual coding experiences with tangible artefacts and behaviours enacted in real-life.

The project lasted two terms, from September to March. 12 children in Year 7 participated in the board game project. The teacher designed the project, identified the learning objectives, aligned it with curriculum objectives and planned the weekly one and a half hour lessons throughout the project duration. The researcher was purely an observer, who attended every lesson, collected the data and communicated with both the teacher and the students to gain qualitative information.

The project brief consisted of building an intelligent board game to be played as a fun, engaging way of revising for history lessons. Tudor-era related content was to be embedded within the board game as revision support mechanisms, such as question cards. Importantly, the board game had to be "intelligent". The students were required to integrate electronic behaviours into the game, with interactive and automated features enhancing the experience. Such "intelligent" behaviours were to be achieved using the SAM Labs electronic kits, in combination with 3D printing artefacts. The students were tasked with building a board game which integrated the SAM

Labs electronics, 3D printing and more traditional materials such as a pizza box used as the game board and colouring sets for design. The project emphasis was set on allowing students to guide their own learning, within the boundaries of the project, using the computational tools available to them with a view to enhance their digital skills and history knowledge. The high-level objective of the project was to both enhance the students' technical abilities, as well as enhance their ability to be independent thinkers, come up with their own ideas, iterate, change and adapt as they advance through the project, as well as getting the project to a viable end.

The board game brief was presented to the students by the teacher as presented below:

- Design a prototype board game which contains "intelligence" – for example it, can sense the player's pieces on the board and create lighting or sound effects which contribute in some way to the playing of the game. The students can research games already available to gain some ideas, but must build a game which will help the revision for the history exam at the end of term
- The students should create a board game in which the interactive behaviours built with SAM Labs blocks are a central feature, and the pupils are able to explain their use of Conditionals, Booleans, and logical operators
- The students can use sensor triggers (inputs) and LEDs, motors or sounds (outputs), or any other available inputs or outputs which are connected and controlled through the SAM Labs app to enhance the board game players' experience
- The students can use 2D/3D computer-aided design (CAD) packages to develop designs for component parts e.g.: counters, players, board accessories, and use computer aided manufacturing (CAM) including 3D printers to make them
- The rules of the board game should be clearly explained, and anyone should be able to understand how the game is played and play it without additional help from the designers

The learning objectives were designed by the teacher as presented below:

- Using research, come up with possible solutions for the creation of the board game elements, and use prototypes to develop the best design possible, then evaluate
- Demonstrate an understanding of the iterative design process
- Understand the concept of 3D printing and the basic functions of 3D printer
- Use a computer program to create a fairly accurate 3D representation of a design
- Understand how more advanced electrical and electronic systems can be powered and used in your design [for example, circuits with light, sound and movement as inputs or outputs]
- Build and develop a product that incorporate systems that make use of for example, sensors to detect light and sound, and control movement using simple actuators
- Demonstrate understanding of conditionals, Booleans, and logical operators

The learning objectives are also reflected in the SeeSaw digital journal the students filled throughout the project. The teacher matched specific entries from students to the objectives she felt it provided evidence of. A screenshot example in Fig 3.2 shows the SeeSaw Learning Objectives page and the corresponding number of entries matched for five students in the early stages of the project:

Both the project brief and learning objectives are extracted from the teacher's "Keble Prep School Year 7 Intelligent Board Game Project Design" specification document, where the objectives are aligned to the national curriculum objectives and the lesson-by-lesson plan of activities are described in detail. The document is attached in Appendix C.

3.3 Data Collection

Data was collected from both learning contexts. The code clubs constituted a preliminary, testing period of partial data collection, whilst the board game project was the principal data collection and analysis context.

	3D Understand the concept of 3D printing and the basic functions of 3D	Build and develop a products that incorporate systems that	Demonstrate an understanding of the iterative design process	Use a computer program to create a fairly accurate 3D	Using research, come up with an initial possible solution for a
[redacted]	1	3	1	1	1
[redacted]	0	0	0	0	0
[redacted]	0	2	0	0	2
[redacted]	0	0	0	0	0
[redacted]	1	0	0	1	4

FIGURE 3.2: SeeSaw Learning Objectives

3.3.1 SAM Labs trace logs

Trace data is data which traces students' virtual actions and is stored in timestamped logs. It is relatively easy to capture, in a non-intrusive manner and at scale, without influencing participants' activity, and critically, capturing process (Berland, Baker, and Blikstein, 2014).

Trace data lends itself as a good candidate to record activity in real classrooms which make for messy, interactive environments. Log information has been previously mined to cluster user behaviours (Liu et al., 2016), identify archetypal users (Wang et al., 2016), and visualise common paths (Liu et al., 2016). Logs are also incomplete records of activity, capturing a single virtual strand of action (Echeverria, Martinez-Maldonado, and Buckingham

Shum, 2019). While logs can account for what users do, they are often limited in the insights they provide on why users act the way they do (Dumais et al., 2014). In response, the learning analytics community is increasingly looking for ways to map 'from clicks to constructs' (Shaffer, 2017; Shute and Ventura, 2013; Wise and Shaffer, 2015). This relates to methodological approaches for identifying meaningful proxies from low-level trace log data to characterise high order pedagogical constructs (Shute and Ventura, 2013; Milligan and Griffin, 2016).

For the purpose of the research project, the SAM Labs development team started logging every version of the students' SAM Labs virtual graphs. The logs started being recorded at the specific request of the researcher, to analyse the changes between versions as a proxy for students' iterative design process. Therefore, every time the students added a new SAM Labs component, removed a SAM block or connection, created new connections between existing blocks or in any way modified the properties of a block, a new version of their SAM Labs graph would be logged in the trace data and timestamped.

The data was stored in a MongoDB noSQL database, following the same format as the rest of the existing SAM Labs application. Each version was recorded as a new entry, containing the following fields:

- ID
- Created timestamp
- Anonymous userID
- SAM Labs project name
- SAM Labs blocks (called nodes in the database) and properties
- SAM Labs connections (called edges in the database) and properties

An example entry is displayed in Figure 3.3.

The data from the subset of students selected for the study was retrieved from the noSQL database, downloaded in XML format and uploaded to a mySQL database for easier manipulation. An example of the table structure is displayed in Figure 3.4.

From the mySQL database, the data was manipulated in different tables using functions and stored procedures to query the required information

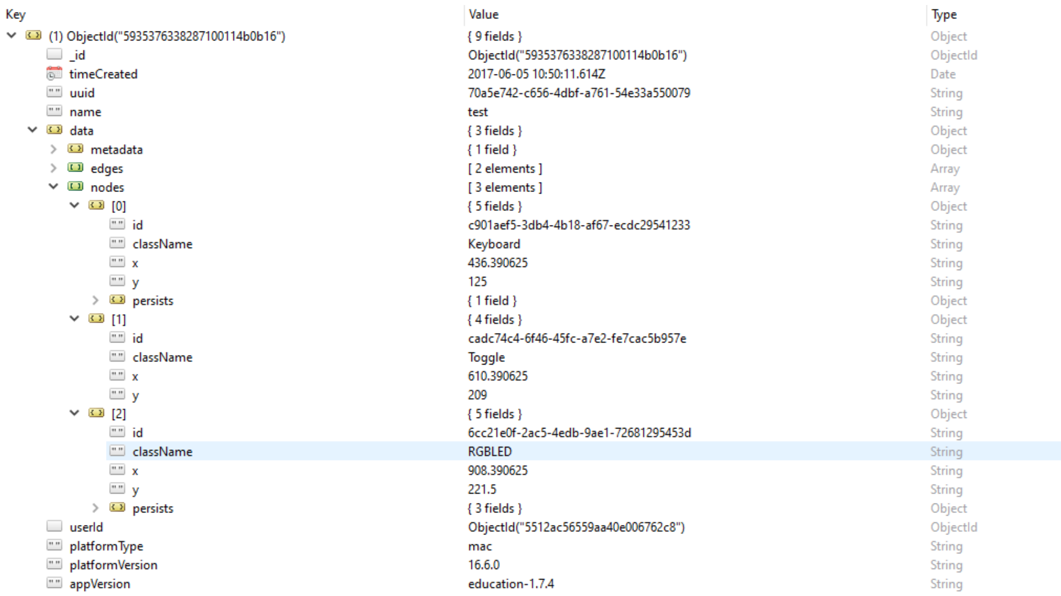


FIGURE 3.3: SAM Labs MongoDB schema

TABLE 3.3: SAM Labs Code Clubs Data

SAM Labs App	Student Input	Teacher Input
Trace Logs	Informal discussions	Informal interviews

more easily, in order to build the data structures underlying the visualisations. The data was manipulated using Jupyter Notebooks, and Phyton data libraries were used to generate the data visualisations.

The Jupyter Notebooks developed by the researcher are attached in Appendix D.

3.3.2 SAM Labs Code Clubs Data

During the code clubs, partial data was recorded to test the collection of trace data, prototype early data manipulation functions and inform the strategy for the second round of data collection. The three main data sources during the code-club sessions are presented in Table 3.3.

The SAM Labs trace logs were recorded, as a test to ensure the functionality worked as expected, and for an initial analysis to be conducted into the logistics of the data manipulation. These we also later utilised to design a first version of data visualisations prototypes. As well as the researcher

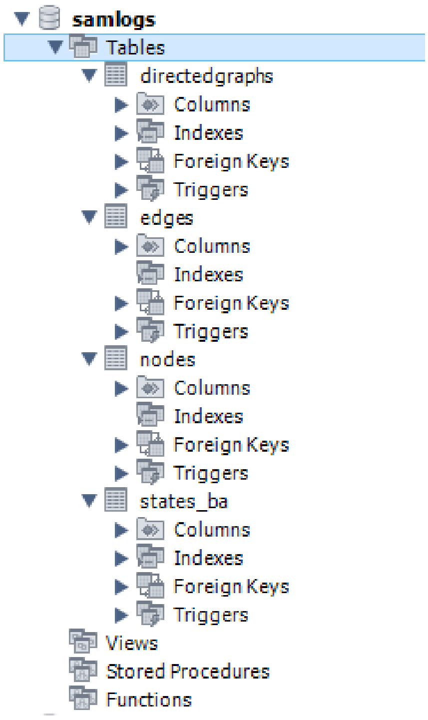


FIGURE 3.4: SAM Labs SQL DB schema

participating in all SAM Labs activities across the six schools, informal interviews were conducted with the teachers and school representatives. The interviews were exploratory and open-ended, targeting the high-level understanding of why teachers feel it was valuable to use the SAM Labs kit or engage with the code clubs, and the type of information they would find useful to track from the students' iterative design. The outcomes of the qualitative observations and the way in which they informed the principal data collection and analysis phase are presented in Chapter 5.

3.3.3 Keble Preparatory School Board Game project

The Keble School Board Game project was the main source of data. The SAM Labs trace data was collected automatically. In addition, the researcher attended every lesson in person for a qualitative understanding of the learning context. The automatic collection of data was complemented by the teacher and student qualitative inputs. The different data sources are summarised in Table 3.4:

- **SAM App** : The SAM Labs trace data was recorded for every student, every lesson

TABLE 3.4: SAM Labs Board Game Project Data

SAM App	Video	Audio	CCTV	Student Input	Teacher Input
Trace Logs	Individual student	Individual student	Group	Digital Journal	Interview

- **Video & Audio** : Individual video and audio were recorded of each student via their webcam. The students worked in their computing classroom, each of them sat in front of a computer screen. Whilst not all their work was screen-based, the webcams were setup to record both the virtual and physical activities the students engaged in. An example of the video recording via the webcam can be seen in Figure 3.5

FIGURE 3.5: Classroom Video Recording via Webcam

- **CCTV**: The classroom was also setup with CCTV recordings, which were turned on for the duration of the project lessons and shared with the researcher. These were used as backup for the individual webcam recordings. An example of the CCTV recording can be see in Figure 3.6
- **Teacher Input**: The researcher recorded multiple conversations with the teacher, with their permission, as informal discussions around the

FIGURE 3.6: Classroom CCTV Recording

teacher's expectations, objectives and assessment of the students' behaviours and performance, as well as structured interviews before and after the lessons recording the teachers' assessment of the project progress

- **Student Input**: Students' individual SeeSaw entries. Student used the digital journals to upload their work, comment on their own progress and commented on each other's posts. And example of a SeeSaw entry from one student's digital journal can be see in Figure 3.7

Given the dynamic, interactive and practical nature of the learning environment, several data sources were used in order to provide a more comprehensive analysis of the primary data source, which were the SAM Labs trace logs. In the analysis, we follow Stevens et al. (Stevens, Satwicz, and McCarthy, 2008) and Duncan & Berland's (Duncan and Berland, 2012) recommendations of combining educational data mining techniques with observational, qualitative analysis to "strengthen qualitative arguments that use discourse analysis by exploring regularities or similarities" (Berland, Baker, and Blikstein, 2014). The data visualisations created using trace log data are interpreted in combination with qualitative audio and visual data, in a bid to improve their meaning by trying to identify how and why students engage in the learning activities as represented in the visualisations (Pardo, Ellis, and Calvo, 2015; Ellis, Han, and Pardo, 2017).

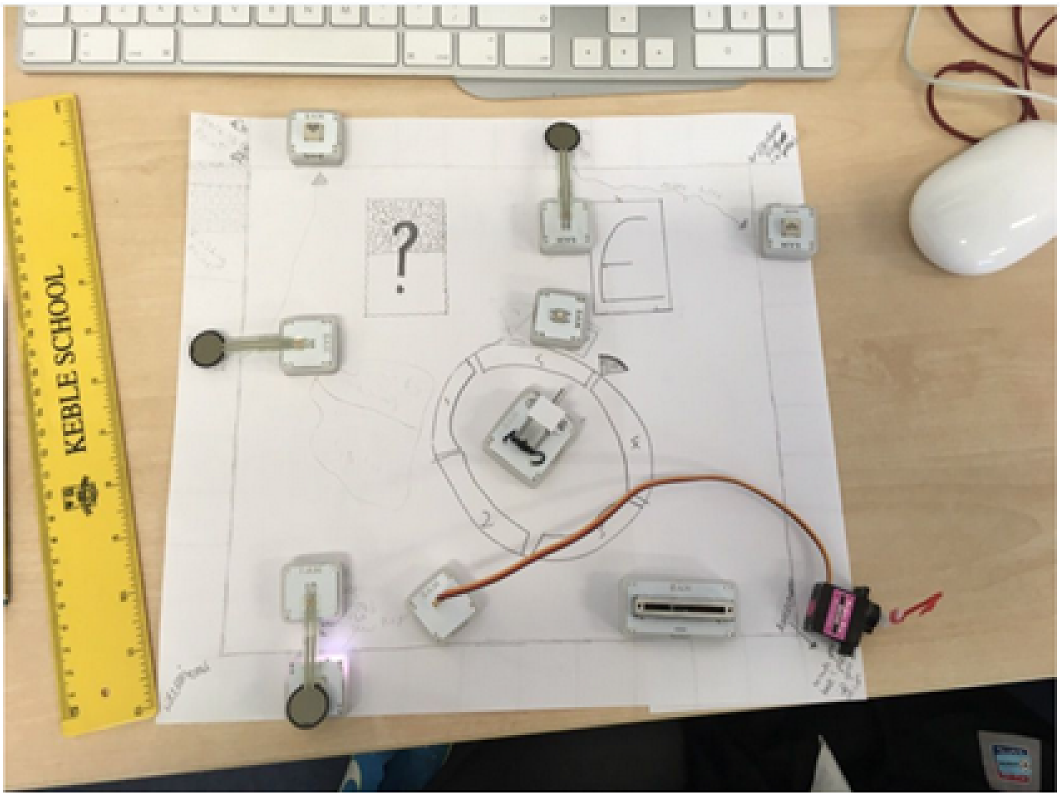


FIGURE 3.7: SeeSaw Digital Journal Entry Example

3.3.4 Teacher Evaluations

In addition to the data gathered on students' iterative design activity from the two learning contexts which served to design and analyse the data visualisations, interview data was also collected to evaluate the data visualisations with ten teachers. All the interviews were conducted online, using the Zoom video-conferencing tool (Zoom, 2022), one-to-one with each teacher. The sessions were recorded in order to produce audio-transcripts for the evaluation analysis, with each interview lasting on average 75 minutes. Further details on the teachers' background, selection criteria and results are presented in Chapter 7.

3.3.5 Data Collection Ethical Considerations

Two research ethics applications were submitted and approved by the UCL Institute of Education Research Ethics Committee.

The first application concerned all the data collected on the students, including the audio and video recordings, trace log data and auxiliary questionnaires and forms. For the application, consent was acquired from the children's parents, and assent was also acquired from the children. For the parents' consent, a participant information sheet was prepared and included with the consent form, outlining the research goals, the data collected and offering parents the chance to get in contact with the researcher, ask further questions or request the publications resulting from the research. The conditions under which data was collected, stored, protected and analysed is detailed in the ethics application form. Given the sensitivity of the data collected and the young age of the students, the researcher reminded the students at the beginning of every lesson that the video and audio recordings are optional, entirely at their discretion. This generated several questions from the students on how the data will be used, and helped build a trust relationship between the children and the researcher. The students were also in charge of starting and stopping the recording themselves, and in control of deleting any existing recordings if they so wished. The application form, participant information sheet, guardian consent form and child assent form are all attached in Appendix E.

In addition to the ethics application, the researcher obtained a DBS certificate through the Institute of Education's DBS application process, a legal requirement for anyone working with children in the UK. Furthermore, the researcher abided by the school policy and for every lesson attended, signed the school registry, obtained a visitor pass and was always accompanied by a school teacher whilst on school premises.

The second application concerned the approval from the teachers who evaluated the data visualisations to be interviewed, recorded and subsequently quoted in the data analysis. A separate participant information sheet was prepared, detailing the research goals, the purpose of the interview and the data collected. The ethics application form, participant information sheet and consent form are attached in Appendix F.

3.4 Design-Based Research Phases

The next section details the application of the Design-Based Research methodology (Reeves, 2006) to conduct and structure the present research, as presented in the following chapters of the thesis.

Design-Based Research (DBR) is a methodology often used in the design and evaluation of innovative and pragmatic solutions to real-world problems, by advocating a strong connection between theory and practice (Reeves, 2006). Design-Based Research is a suitable approach for the present research study, given its emphasis on pedagogy and learning behaviours ahead of technology. Design-Based Research embraces the complexity and constraints often present in educational real-world contexts, supporting the development of authentic, context-aligned solutions (Cotton, Lockyer, and Brickell, 2009; Reeves, 2006). Furthermore, the Design-Based Research methodology is used as a bridge connecting the theoretical aspects of appropriation and iterative design to the practical data analysis process, contributing towards what Reimann positions as 'a more theory-oriented Learning Analytics' (Reimann, 2016). The DBR approach is structured across four research phases:

1. **Phase 1 – Discovery**: Analyse and define a practical educational problem
2. **Phase 2 – Implementation**: Explore and implement solutions informed by theory and real-world observations
3. **Phase 3 – Evaluation**: Evaluation of the implemented solution(s)
4. **Phase 4 – Reflection**: Document the evidence and use it to inform the redesign of the solution in future research phases (Barab and Squire, 2004)

The next few sections describe what each phase entailed for the present research, including each phase's objectives, activities and outcomes, summarised in Table 3.5.

Design-Based research usually evolves in an iterative way, through the creation and evaluation of prototypes in authentic settings (Anderson and Shattuck, 2012). The data visualisations developed as part of this research are positioned as prototypes to be tested with authentic teachers. In addition, the research evolved iteratively, with each phase informing the next (Reeves, 2006). Finally, the iterative nature of the Design-Based Research approach is also applied in the presentation of the research contributions. The findings are presented as starting points for further investigations into the use of data visualisations for representing students' learning as a process, with emerging questions and improvements identified for future exploration.

TABLE 3.5: Design Based Research Phases and Research Questions

	RQs	Activities	Outcomes
Phase 1 - Discovery	RQ1: How can trace data be used to visualise the evolution of students' SAM Labs designs?	Appropriation Model Data Visualisations Prototypes	Reconciliation of practical and theoretical aspects of the students' iterative design process Operationalisation of the iterative design process across data proxies
Phase 2 - Implementation	RQ2: How can visual representations of students' evolving designs be used to characterise the iterative design process?	Data Visualisations Analysis	Insights into students' iterative design behaviours
Phase 3 - Evaluation	RQ3: How can visual representations of students' evolving designs support teachers' understanding of students' iterative behaviours?	Teacher Evaluations	Feedback on supporting the guided reflection process through data visualisations
Phase 4 - Reflection	What implications can be extracted for the future development of data visualisations to support the iterative design process?	Identification of implications for the design of data visualisations to support the iterative design process	Design implications for data visualisations to support the iterative design process

3.4.1 Phase 1 - Discovery

An initial discovery stage was undertaken to refine the research questions and inform the data collection and analysis. Informed by the literature review presented in Chapter 2, the first research phase consisted of exploratory school visits to better understand the practical context in which physical computing kits are being used. The school visits are presented as Learning Context 1 earlier in the present chapter. These were undertaken with the aim of understanding the practical realities of teaching and learning with physical computing kits, and the specific ways in which the kits provide pedagogical value. The researcher's observations were focused on aspects of the iterative design process as the primary pedagogical interest of the present research. The findings of how the iterative design process unfolded as students and teachers interacted with the physical computing kits informed the subsequent data collection and analysis research phases.

Objectives

The school visits were undertaken to observe first-hand the students' experiences when building with the SAM Labs kit. The goal was to better understand the ways in which the kits' theoretical and design goals materialise practically, and to consider how learning analytics might help given the context's nature and needs. Informal conversations with teachers and classroom observations contextualised the research's background literature, as well as informing its research questions and goals. Specifically, this phase informed the problem definition (Reeves, 2006) and the data visualisations requirements from the teachers' perspective. This phase helped formulate data visualisation design goals grounded in the practical realities of using the SAM Labs kit in the classroom. Three main questions guided the first research phase:

- How does the iterative design process practically materialise in the classroom using the SAM Labs physical computing kits?
- How does the open-ended nature of iterative design tasks align to the related theoretical concept of appropriation?
- What data proxies can be used to explore aspects of the iterative design process in open-ended learning contexts?

The intention was to inform the practical realities of the literature findings and align the goal of the visualisations with the goals of the teachers in the way physical computing kits are perceived and used.

Activities

The first discovery research phase's objectives were met by the school visits presented in the first learning context. Both the code club activities organised in the schools with no previous experience of physical computing kits, as well as the visits to the schools who had integrated the use of the SAM Labs kit within their own curriculum structures, formed the grounding for the first discovery research phase.

During the code clubs, particular attention was paid to the ways in which students maximised the open-ended affordances of the activities, which were further correlated with the literature findings on appropriation and iterative design. Notice was taken of the ways in which the students customised their artefacts in comparison to what was shown to them by the SAM Labs representatives, as well as the way in which they would distinguish themselves from their peers. Students' behaviours were observed relating to their formulation of their own goals and evolution of their artefacts within the remit of the project brief and SAM Labs functionality.

During the visits to the three schools already using the SAM Labs kit, the reasons why teachers chose to buy and use the physical computing kits were investigated, as well as the ways in which teachers designed learning experiences which incorporated SAM Labs. The teachers were interviewed on the learning objectives they targeted when using SAM Labs, as well as the ways in which they currently supported those objectives practically in the classroom. These led to questions and insights around the ways in which learning analytics might support the practical ways in which teachers already scaffold the iterative design process.

Outcomes

The school visits lead to three main outputs presented in Chapter 5 of the thesis. First, a qualitative description of the ways in which students engaged with the SAM Labs physical computing kits in relation to the iterative design process in an open-ended context is presented at the beginning of Chapter 5

Second, the practical nature of students' iterative design process to reach their own self-constructed goals is reconciled with theory in the appropriation model presented is Section 2 of Chapter 5.

Finally, the learning design of the SAM Labs activities was mapped to learning analytics dimensions in a series of steps presented in the third and last section of Chapter 5. A quantitative ethnography approach was used to align the activity proxies with the SAM Labs trace data represented over time. A series of prototypes were designed, aimed at enabling different ways of exploring the students' iterative design process in open-ended contexts, accounting for individuals' appropriation. The data visualisation prototypes are presented in Section 3 of Chapter 5. The resulting visual representation were used in the next research phase to investigate the students' iterative design activity.

3.4.2 Phase 2 - Implementation

The second research phase entailed using the data visualisation prototypes to explore the students' iterative design behaviours, informed by the findings of the first research phase and the appropriation model. The design of the data visualisation prototypes was aimed at representing the students' iterative design activity to support the guided reflection process between teachers and students. Aspects of the iterative design behaviours were identified as they emerged from the visualisation prototypes to inform the evaluation stage, and patterns were identified across multiple students and projects.

Objectives

The main objective of the second research phase was to conduct an initial exploration of the students' behaviour as it emerged from the visualisations. The aim was to characterise the students' iterative design activity as it materialises in SAM Labs open-ended projects. The visualisations are positioned as "objects to think with" for teachers to evaluate their potential to support guided reflection in open-ended learning activities using physical computing kits. The questions leading the second research phase were:

- What aspects of the students' iterative design process emerge from visual representations designed using SAM Labs trace data?

- In what ways are the theoretical and practical design considerations materialised in the visualisations when analysed across multiple students and learning activities?
- What patterns emerge from the data visualisations on the students' iterative design behaviours?

Activities

The findings from the first research phase were used to formulate a data collection and analysis strategy which were applied to Learning Context 2. For the data analysis, the trace data visualisations were complemented by the learning design documentation produced by the teacher as well as video and audio recordings of the students from Learning Context 2. The learning design documentation included a breakdown of the individual project learning objectives as well as lesson by lesson plans. The video and audio recordings provided an extension to the trace data representation analysis. The visualisations were analysed against the visualisations' design goals and theoretical links to appropriation and iterative design behaviours.

Outcomes

First, seven students' iterative design journeys constructing SAM Labs artefacts are presented, triangulating the information emerging from the visualisations with the video, audio and digital journaling data. Second, three dimensions characterizing the students' iterative design process are presented. Third, iterative design patterns emerging from the data visualisations from all students are discussed in the context of iterative design pedagogical concepts.

The analysis investigated both the extent to which the visualisations accurately correspond to the theoretical and practical foundations they were built on, as well as their potential to uncover new insights into the students' iterative behaviours. The analysis identifies emerging patterns from students' iterative design activity, as well as supporting evidence for their appropriation behaviour.

3.4.3 Phase 3 - Evaluation

The third research phase focused on using the visualisation prototypes to explore the potential for using data visualisations to support guided reflection with teachers. A subset of the visualisations generated during the second research phase was presented to teachers, who evaluated them in terms of what they communicate and the ways in which they might be used as reflection tools.

Objectives

The teacher evaluations were undertaken with the purpose of identifying the ways in which the visualisations adhere to their intended goals, as identified across the first two research phases. The following questions guided the analysis and evaluation third research phase:

- How do teachers interpret the information in the visualisations and what aspects of the students' iterative design process do the prototypes prompt teachers to discuss in detail?
- What potential do the visualisations hold for supporting the guided reflection between teachers and students aimed at improving students' iterative behaviours?

Activities

The social translucence framework was used to evaluate the visualisation prototypes with teachers. Ten teachers were presented with a subset of the visualisations produced for four students participating in the board game project. The teachers were interviewed across the three social translucence dimensions: visibility, awareness and accountability.

Outcomes

Two main outcomes arose from the third research phase. First, teachers' perspectives on the students' iterative behaviours were explored and contrasted with original design intentions. Additional insights generated from discussing the students' iterative design process using the concrete visual format were derived. Second, the potential for the data visualisations to support guided reflection were investigated from teachers' answers. These findings are presented in Chapter 7 of the thesis.

3.4.4 Phase 4 - Reflection

The fourth and final research phase summarised the findings from all three previous research phases to identify possible design implications for using data visualisations as tools to support guided reflection of the iterative design process in open-ended learning tasks using physical computing kits.

Objectives

The purpose of the final research phase was to identify transferable ideas which could be applied to the design of data visualisations with similar goals, the design of open-ended learning experiences, as well as directions for future research. The main questions which guided this final stage were:

- What implications for data visualisation design can be extracted from the research findings?
- What implications does the construction of data visualisations aimed at supporting students' iterative behaviours have on the design of learning experiences?

Activities

The research findings are used to document the implications for both learning design and learning analytics, alongside directions for refinement of the solution in future research. Implications of the design of data visualisations towards quantitative forms of representing the iterative design process are presented.

Outcomes

Chapter 8 encompasses the fourth research phase, presenting reflections on the implications of designing data visualisations, informed by educational research, closely aligned with practical learning contexts, towards the better understanding and support of educational goals in the context of open-ended practical learning using physical computing kits.

This chapter has explained the methodology used to answer the research questions. The next chapter presents the outcomes of the first phase of the research and the first thesis contribution. In Chapter 4, insights from classrooms where students engage with physical computing kits in open-ended construction challenges are presented, and further linked to educational theory. Appropriation is framed in the context of students' iterative design behaviours observed from the classroom, and a model is presented used to inform the design of the data visualisations and analysis later in the thesis.

Chapter 4

Student Iterative Behaviours

This chapter presents the qualitative observations made during the researcher's participation in the two learning contexts where trace data was collected, as presented in Chapter 3. The observations contribute to the understanding of the practical implications of learning with physical computing kits in schools and inform the definition of the educational problem addressed in the thesis. This chapter addresses the alignment of the practical evidence resulting from the learning contexts with the theory of appropriation. The iterative design process is aligned with the theory of appropriation, resulting in a theoretical model used to guide the data analysis and interpretation later in the thesis.

4.1 Problem Definition

The first section of this chapter is a summary of the qualitative observations gathered during the school visits presented in Chapter 3. The observations provide evidence for the educational problem the thesis is positioned to answer, detailing the students' iterative design behaviours as they emerge in authentic settings. The observations described below are summarised from the researchers' notes during their participation in the two learning contexts. Two sub-sections describe on one hand, the students' iterative behaviours, and on the other, the teacher's priorities in supporting the students' construction process. The section ends with conclusions on the way in which students approached the construction of their SAM Labs designs, leading to a set of data visualisation design goals reflective of the evidence emergent from authentic learning contexts.

4.1.1 Student's iterative behaviours

The first part of this section presents observations of the students' iterative behaviours over the 6 weeks of code club activities and school visits. The findings presented here are a summary of the full "SAM - introduction into schools.docx" document which is listed in Appendix J. It was created at the end of the pilot-phase school visits and code clubs run as part of the discovery process of the first research phase. The document provides a holistic review of the code club activities and their outcomes across several aspects relating to the students' engagement with the SAM Labs kit, in addition to observations related to their iterative design behaviours. The summary presented below is restricted to aspects of students' iterative design, to inform the data collection and analysis strategy which focuses on supporting the guided reflection of students' iterative design behaviours. Specifically, we detail the ways in which students construct their own goals within the boundaries of the given task, and the ways in which they tested and adapted their constructions with the aim of achieving those goals.

Four aspects related to students' iterative design behaviours are presented. These were documented by the researcher during the first Discovery research stage, as a result of their direct participation in the two learning contexts. Notes were taken on the recurring aspects of the iterative design process, which repeated themselves across the different students and different schools. Over time, the four aspects summarised below were identified as consistent aspects of the students' iterative behaviours.

- Instant feedback: the effects of the instant feedback which the kits provide students with after each iteration
- Iterative behaviours: the specific ways in which students iterate between versions
- Goal formulation: the type of goals students formulate and adapt in response to the feedback returned from each iteration
- Difficulty in articulating the thinking process: the challenges in capturing the evolution of students' designs

Instant feedback

The SAM Labs kit allows students to create electronic circuits that, in real-time, translate into working physical analogue behaviours. This instant feedback, available immediately to the students, from the most basic starting circuits to more complex behaviours, allows students to see the results of each of their actions in practice, helping to sustain engagement. The impact of physical computing kits' instant feedback observed during the code clubs aligns with Resnick and Silverman's findings in their study on designing construction kits for children (Resnick and Silverman, 2005). The SAM kits "make it as simple as possible – and maybe even simpler" to build a basic working circuit, adhering to the "low floor and wide walls" principle of starting quickly and easily, whilst having the scope to progress in a variety of directions, moving towards complex behaviours (Resnick and Silverman, 2005).

Whilst not all students reached the same level of sophistication of the weekly set challenge, all students were able to present a working version of the artefact. This was used by the code club moderators to maintain a positive attitude towards each challenge, and encourage students to engage every week, with the guarantee of ending with a working artefact. During each lesson, all students would remain engaged with the SAM Labs kit, at the very least at a basic level of remaining focused on their task and not engaging in any other activities. This allowed the researcher to observe their ways of interacting with the kits without worrying about the students getting off-task.

The physical nature of SAM blocks was another contributing aspect to the students' engagement in the code clubs. The fact that the children could physically play with the blocks, create tangible behaviours which they could see in action, touch and feel the motor wheel spinning, light turning on, or press of the button contributed to the type of experiments the children would conduct, and their vocabulary when describing their actions. Their goals were formulated around behaviours in the physical space and connected to known physical characteristics, for example: navigating the SAM Labs car around the classroom desks where their friends sat or lighting up the flashlight when their easily scared peers would get it close enough to their faces. This allowed the focus to remain in the physical world, with the virtual circuit construction as the means of getting the required behaviours working, a vehicle for translating computing instructions into real world actions. The students used the physical properties of the blocks to formulate goals aligned with their personal circumstances and interests, such as creating an alarm system akin to a disco-ball, programming their cars to explore corners of the classroom they could not themselves reach, or incorporating house alarm features that catered for their home-owned pets.

The instant feedback provided by the SAM Labs kit helped sustain the students' iterative behaviours, with students constantly adapting the virtual circuits and testing these effects in the real world against their own expectations. The context allowed for the students to be observed in a real-world setting, making the iterative design behaviour transparent in a qualitative way. This served as information to complement the trace data which logged each change the students made practically to their constructions.

Iterative Behaviours

During the code clubs, particular attention was paid to the ways in which students iterated during their constructions to achieve their set goals. Specifically, the ways in which the students adapted their virtual circuits to change how their artefact behaved in the real world. The observations included the ways in which the students abided, or not, by the SAM Labs construction rules as they evolved their constructions, as well as the reasons why students made the changes they did. Three types of iterations could be observed:

1. Iterations between distinct blocks to check their functionality and "see how they work"
2. Iterations between blocks and connections to get a specific part of the circuit to function
3. Iterations between blocks and connections to match a specific conceptual behaviour

The main construction principle when working with the SAM Labs kit is the input -> connection -> output structure, which any circuit needs to be built by to function. This was re-enforced at the beginning of each lesson, with the examples always emphasising which blocks constitute the input, which blocks are connectors, and which function as the output. Once the structure is well understood, the students can mix and remix the inputs with different connectors and outputs to generate the desired behaviours.

There are two types of mistakes which can occur whilst building the virtual circuits, both pertinent to the required input -> connection -> output structure. First, if the order of blocks is in any way broken, either leaving the input out, or starting with an output, or going from the input -> output -> connector and expecting the connection behaviour to affect the circuit. Second, if the structure is abided by, but the sequence of blocks cannot interpret each other's instructions. For example, not every input can be followed by any connector, or any connector followed by any output. Each block in the circuit needs to be able to interpret the instruction of the previous block in the sequence. Therefore, connecting a Button to a MorseCode block won't have any result, because the MorseCode requires a message to interpret and transform into signals, usually specified in a Text connector. In other words, the MorseCode cannot interpret the on/off instruction the Button is only able to output.

The input -> connection -> output structure was incorporated into the students' experiments in stages. Initially, despite SAM Labs expert demonstrations, a majority of the students would often rush to add as many blocks as possible onto the virtual canvas, and start connecting all blocks to each other, in no particular order or logic. The input -> connection -> output idea had to be reiterated repeatedly for students to start following it. Often, the students would often struggle to identify whether a specific block would be an input, connector or output. Appreciating the very concepts of an input, connection and output constituted a learning curve for most students, which they overcame by connecting the blocks in any way until they got a functional response. Once the students started to better understand what input, connection and output meant, they were able to conduct experiments more easily to identify the functionality of each block. Therefore, a lot of the students' experiments consisted of them connecting blocks in any random order, and refining the connections until the input -> connection -> output structure was achieved and a functional response generated by the physical blocks. Blocks connected in an incorrect order, or missing an input or output altogether were the most frequent errors made by the students as they worked on their constructions.

For those students whose' understanding of the circuit structure increased, the complexity of the circuits also increased. For example, with new outputs such as ServoMotor or Camera, the students would start testing them out by directly connecting them to an easy-to-use input, such as a Button, just to test out their basic functionality. Once they saw for themselves how the output behaved, they would start incorporating more complexity into the circuit and come up with behaviours they might want to achieve with the new output.

Once the input -> connection -> output structure was established between a few blocks, the students would often swap out blocks in turn, to discover their functionality in different circuit sequences. This type of experimentation generated the second most common error, as the students would often try to connect blocks which were not able to interpret each other's instructions.

Finally, a third type of the students' iterations focussed on the specific behaviours the students were looking to implement. Once the input -> connection -> output structure was correctly applied and the blocks in the circuit able to understand and act upon each other's instructions, the students would test different ways of activating the physical blocks aligned with their goals. For example, to achieve the disco ball alarm system, once a button was connected to the light output through the colour randomiser connector as the basic circuit, one of the students started experimenting with different sensor inputs and timing connectors to change the behaviour of when and how the alarm got triggered.

The three experimentation stages: achieving a correct input -> connection -> output structure, testing the valid sequence of blocks which understand each other's instructions, and switching blocks in and out to achieve different behaviours were the main three types of iterative activity observed during the code club lessons. None of the children approach their testing as a step-by-step procedure where they understood everything at every stage, to which they would add additional elements. Neither did they go through the experimentation stages described above in a linear order. Instead, they were guided by their goals and the type of components they believed were required for construction. A more systematic approach to the testing was observed in the contexts where three schools had been using the SAM Labs kit for over 2 years, where more students seemed to understand each step well before proceeding to the next.

The most frequent support given by the SAM representatives was to encourage students to either simplify the circuits they had on their canvas, so reducing the number of blocks they were working with to more easily troubleshoot, or repositioning the blocks from left to right according to their type: input, connector or output. This way, the students were able to try out different combinations and learn their effects for themselves, without being told directly what worked and what did not. The simplification and repositioning advice helped the students debug the circuits by themselves, identify how the blocks worked and what exactly they wanted to achieve.

Goal formulation

The students choosing the specifics of how they would implement a specific construction design, within the boundaries of set functionality rules, influenced the type of experiments and goals that students subsequently engaged in. Despite multiple malfunctioning circuits built during their experimentation, most students seemed to thrive on the possibility of finding out for themselves whether an idea would work or not, often actively avoiding the help of a supervisor in order to avoid interference. During the code clubs, when it was possible for some students to leave the classroom for more space to test their prototypes, either sound-related or seeking floor movement space, they would happily do so whilst remaining fully engaged with the SAM kits. In one instance, the teacher had to follow a group of students outside the classroom to check on progress. The students reacted in a protective way, almost shielding their constructions from the teacher in order not to interfere with their in-progress ideas and experiments. The feelings of personal ownership over their own projects would often lead to a willingness to persevere through mistakes and bugs (Kafai, 2016).

When offered alternatives or suggestions for changes, usually the students would consider them, if these contributed to their already existing goals. On the other hand, adjustments to their ideas, coming from external sources, unless aligned with what they wanted to achieve, would often be dismissed. For example, when advised that a buzzer would be a suitable addition to her disco light to trigger a fire alarm in a smart building, a student dismissed the idea, given that she was, at the time, focusing on randomising the colours of her disco ball. However, when advised that the RGB LED component could, in fact, output any colour rather than just red, green and blue, the student immediately turned her attention to taking full advantage of the newfound feature towards her randomisation goal. Such behaviours suggest a keen attachment from the students towards the ideas they came up with themselves over third-party suggestions, regardless of their feasibility or suitability for the project. In addition, once the students generate feasible ideas they can test, they demonstrate a long-term commitment and interest in getting them to work, and an almost protective attitude from any potential external interferences from teachers or peers (Barak and Zadok, 2009).

The students' protective attitude towards their goals also manifested in their own comparisons against their peers. Whilst ideas such as the flashlights for the car or automatically triggered music for their smart houses were shared amongst multiple students, each student was keen to separate themselves with unique features. Some students triggered their flashlights based on light sensitivity in the environment, others based on proximity to other objects. Some students used music as a deterrent against thieves, whilst others as party invitations for their neighbours, changing the triggers and outputs accordingly.

Due to the distinct constructions, each student encountered unique challenges. Debugging these involved a process of isolating issues and iterating through potential fixes. By testing and iterating the artefact, students draw comparisons between the formalization and the perception of the actual movement (Katterfeldt, Dittert, and Schelhowe, 2015). Whilst some students were frustrated with the process, for others, the ownership over their unique design drove them to persevere often beyond the teachers' suggestions. This showcases the strong link between the students' opportunity to personalise their designs and the natural process of troubleshooting and iterative design this leads to. The personalisation available in open-ended projects further enhanced the iterative design process (Fields, Lui, and Kafai, 2019).

Difficulty in articulating the thinking process

Whilst open-ended learning environments using responsive physical computing kits offered the space and time for students to formulate goals and hypotheses, test these for themselves and refine based on feedback, students often found it difficult to articulate their thinking process or reasoning guiding their actions.

Students often acted in line with aims they were unable to consciously articulate, iterating through versions without a concrete plan of what would get them to the desired behaviours. Some students would articulate goals which they had no tangible vision of how they might be practically implementing using the SAM Labs kit, for example building a flying car without any thoughts on how to build in flying capabilities. Other students would be focused on experimenting with the blocks and circuits themselves, without clear intentions of what functionality they were aiming to construct. They would simply swap blocks in and out, or change the circuit sequence to test the resulting effect on the physical blocks, without a construction goal. Other times, the goals and experiments seemed disconnected, with the students conducting experiments with circuits which couldn't feasibly lead to their functionality aims. For example, experimenting with the Direction and Switch Direction blocks to change a car's direction, when trying to implement a Start/Stop behaviour.

These observations match Barak and Doppelt's findings of students' difficulties in explaining their work in process, as well as their reluctance to document it. The students had predominantly used trial-and-error, patching and tinkering to arrive at inventive solutions (Sternberg and Lubart define an inventive idea as being original, surprising and useful (Sternberg and Lubart, 1999), but would often have trouble explaining how they arrived at their designs (Barak and Zadok, 2009).

The majority of students were reluctant to discuss their mistakes, or admit to their lack of concrete construction plans. Students also found it difficult to showcase work that they knew would change, and not as final as they envisioned it to be. Finally, for some, discussing the intermediate steps was simply an unnecessary activity, a mere distraction from their constructions. Students articulating their thinking process constitutes a skill in its own right which can be difficult to master. Juggling not only the design and construction tasks, but also working towards articulating their thoughts, which they are not always aware of, or lacking the skills to present their work effectively proved to be difficult during the code clubs. Barak and Doppelt conclude that unless specifically supported to do so, students do not naturally tend to explain their thinking process or report their difficulties (Barak and Zadok, 2009). Therefore, it is important to find ways to emphasise the important of documenting their journey and find ways to enhance their record keeping in a way that helps students practice identifying and explaining their ongoing thinking processes (Barak and Zadok, 2009).

Often the SAM representatives, in a bid to help, especially when students were not able to clearly express their goals or thinking process, would stop students in their tracks and replace their experimentation with different goals and clear construction pathways. For example, they would try to scale back a "car flying" behaviour with ways of increasing the car's speed.

Whilst more feasible, the two goals are distinctly different in terms of end-product, as well as their SAM Labs construction. However, stopping the students in their tracks not only left their previous hypotheses unanswered, but would potentially set the students on a path that they hadn't decided to work on, therefore finding it hard to continue. Other times, when the SAM representatives took the time to better understand at least partly the students' intentions, they were able to build on those and scaffold those towards more feasible experiments or effective paths, but critically building on the students' thinking process up to that point. For example, when trying to construct a colour filter for a student's Selfie Photo system, the SAM representative suggested experimenting with the LED RGB values, in a bid for the student to realise that a true colour filter with the effects they were trying to implement was impossible. The student continued to attempt different versions, eventually settling on a scaled back version of their original goal, with great satisfaction.

In line with this observation, the teachers placed more value on helping students expressing their reasoning process rather than the characteristics of the final solution they might produce in the end. They would not question the students' desire to build a flying car, but the process by which they would get there. The teachers focused on helping the students articulate their goals and identifying the relevant experiments that would help test their hypotheses, rather than trying to change their intentions.

4.1.2 Teachers' priorities

The second part of this section consists of the insights gathered on the reasons teachers used the SAM Labs kit in their classroom, their expectations of what students would achieve with the kits and the practical ways in which they would design learning activities and support the students through them. We differentiate between the two learning contexts: the code club schools who had never used the SAM Labs kit before, and the more experienced schools who had been using the SAM Labs kit for over a year, integrated in their computing curriculum. The discrepancy between the teachers' attitude, knowledge and goals in implementing the physical computing kits in their teaching between the two contexts is explained below.

Code club schools

The three teachers at the three schools where the code clubs were organised were very keen for their students to engage in the code club activities. The teachers were happy to put in the required effort to facilitate the required equipment, space and time to conduct the code clubs. The schools had limited experience with both computing and physical computing kits. This welcoming attitude was underpinned by an instinctive excitement on the teachers' part about physical computing kits similar to SAM Labs. The teachers were interested in the kits' value for teaching computing, a new and engaging way of getting children interested in technology, the kits' interactivity and easy of use for after-school activities, and perhaps an influence from the recent general hype around similar kits used increasingly in schools.

Whilst all teachers were extremely welcoming to the code clubs being run, and organised the timings of the activities for their students, their subsequent engagement in the activities themselves did not match expectations. The teachers were happy that "experts" were coming in to run the clubs, without having to run them themselves. At times, the teachers would even leave the classroom altogether during the activity or focus on work for another part of their teaching. This was counteracted by the code club organisers who requested teachers' active participation in the activities, increasingly handing over the main facilitating role to the teacher as the sessions continued, with the last code club being entirely run by the teachers themselves, with the passive assistance from the SAM Labs representatives. The teachers consistently referred to the lack of time and expertise as reasons for not being more proactive in their code club engagement. They did not feel they had the expertise required to engage with the kits, despite these being new for the students as well. This aspect points to the teachers' expectations terms of the level of knowledge and experience they deemed necessary to acquire, to be ready to teach specific concepts or using specific tools. Despite having the opportunity to learn about the kit alongside their students, they didn't feel that would suffice to continue the activities without the SAM Labs "experts" there. The lack of expertise was often compounded by the lack of time teachers cited, to gain expertise in their own time, research the kits and understand them away from the classroom, before feeling ready to integrate them into the classroom on their own. By the end of the code club series, two of the five schools who were already doing some computing teaching continued utilising the kits independently, while the other three schools interrupted their use. Whilst all schools felt the code clubs had been beneficial to organise, the three schools who stopped using the SAM Kits felt they didn't have the time or capacity to continue independently. All schools however were very happy to continue engaging with the SAM Labs team, continue being "champion" schools for user testing or other code club series. This is consistently observed in literature which documents teachers' lack of computing expertise leading to their lack of confidence in supporting students learning something they are not fully familiar with themselves (Kafai, 2016).

The second observation which followed the teachers' initial enthusiasm for physical computing kits was a lack of detail around the reasons for their interest. When questioned on the specific potential they saw in their students learning with physical computing kits, teachers pointed to the students' enthusiasm for interactive tools, or increased exposure to computing concepts. However, the teachers struggled to see where exactly the kits could fit in their current curricula or the ways in which they would integrate them more deeply in their day-to-day teaching. They saw the kits as extra-curricular, "fun" tools to play with, hopefully leading to some computational learnings, but very much separated from the formal schooling structure and content.

Finally, from the perspective of identifying useful data analytics to be designed within code club contexts using physical computing kits, the teachers were further pressed to describe the type of information they would be interested in further analysing about their students' behaviours because of participating in the code clubs. However, without any example prompts from the researchers, or choices to select from, the teachers were unable to articulate more precisely what they felt the potential of the code clubs held for their students. Whilst the enthusiasm and interest were clear, the specific goals they were hoping to achieve were less clear. The teachers let the code clubs unfold exactly as they had been designed by the SAM Labs representatives, without any prerequisites on the content they would prefer to be covered, or the way in which the code clubs were structured. Whilst the teachers associated the code clubs with other project-based activities they were themselves running, they commented that they did not have a clear structure for running their projects, or clear evaluation schemes, which is why they would only use them for "non-academic" purposes, outside the formal schooling schedule. The teachers did not feel they had any authority on providing recommendations to the SAM Labs representatives, despite them being the pedagogical experts who best knew the students. Instead, they felt they had all the learning to do, both in terms of how the kits operated, as well as how these might be used pedagogically.

Sam Labs user schools

The three schools that already engaged with the SAM Labs kit welcomed the visits as an opportunity to showcase and review their use of the kits with people who design and conduct research around the kits. It quickly became clear that the schools' integration of the SAM Labs kit was part of wider transitions the schools had undertaken to better integrate computing and technology into the classroom, both within the standard curricula as well as inter-disciplinary activities. All teachers reported their current use of the kits being the result of at least two years of careful planning and thought around how to integrate physical computing kits into their teaching in a holistic manner, within an ecosystem of other tools and learning experiences aligned with pedagogical goals. In addition, all schools had dedicated technical staff whose responsibility was to investigate and maintain all relevant equipment the children needed for the learning to include various technologies. Importantly, all schools had a "technical" champion, a teacher who was particularly interested in acquiring various technologies and finding ways of integrating them into the students' learning. These teachers were usually the ones who had developed an initial interest in physical computing, had researched the various options and acquired the SAM Labs kit, and the ones who thought most about the most meaningful ways of integrating them into the classroom. They were also the ones to present the kits to the other teachers and facilitate their use across different subjects, and to enable their holistic integration into day-to-day teaching as well as in extra-curricular projects.

When asked about the value they saw in the SAM Labs kit, teachers pointed to the following aspects:

- SAM being an easy introduction into computing, suitable for young children, starting with Year 5 students
- SAM being a suitable tool to use as part of the technology design classes and promote computational thinking and making skills

- SAM being a good tool to embed logic and coding concepts in fun, creative, practical projects
- SAM being a relevant tool to engage students in problem-solving and creative thinking activities

Their purchase was also driven by a desire to present students with tangible robotics, which they can correlate to their software programming and extend to the physical environment. They were keen to enhance the Technology Design classes with physical computing kits which allowed the children to take more control over the design of their artefacts, in parallel to other tools like Lego and 3D printing. Critically, they were attracted by the ease of use, low-level entry required for understanding and integrating the tool into their computing classes, as well as the open-ended capabilities. The teachers were specifically attracted by the possibilities of their students engaging with the tool creatively, thinking about what is possible to build and making their own designs according to their own interests and passions. The teachers were most interested in the creative potential of SAM Labs, of the tool supporting students working logically and sequentially, reaching a goal via trial and error. All teachers used the kits for their computing lessons as well as in interdisciplinary maths, science and arts projects, identifying uses across the STEAM spectrum.

The teachers also drew parallels to other project-based learning experiences they would design for students in subjects other than computing, that they associated with the SAM Labs code clubs. They pointed to the children's increased engagement when learning with tangible tools as a way of putting abstract concepts into practice. They also felt that project-based learning experiences allowed them to give students more freedom to explore certain ideas, in a way that allowed them to put their own ideas into practice. Finally, the interactive nature of practical learning experiences appealed to teachers as a way of getting students to become more comfortable with mistakes. They would distinguish between the code club students that would "love" the experience, because they were willing to "try things out", and those who would potentially enjoy it less given their reluctance towards failing, or even expressing their ideas in the first place.

In comparison to the three schools where the code clubs were run, the teachers who were already using the SAM Labs kit had a more precise vision of why and how the kits could be used with the students as presented above.

However, even in the more advanced setting, whilst the potential and vision for the kits was clearer and better defined, the structure and evaluation of the SAM Labs activities remained high level and varied across different settings. In addition, whilst the code club teachers emphasised the computational concepts that they felt the students had engaged with most, the teachers who had proactively chosen the SAM Labs kit for their schools were more focused on the more general problem-solving and iterative design processes students engaged in. This led to a challenge in identifying concrete and quantifiable aspects of the learning experience that matched the teachers' vision of what skills physical computing kits such as SAM Labs promoted.

The teachers did point to specific frameworks and resources that guided their integration of the SAM Labs kit in their teaching. One of the three teachers pointed to "The Framework for Maker-Centered Learning" (MakerEd, 2022) alongside the 'Innovate Inside the Box: Empowering Learners Through UDL and the Innovator's Mindset' book (Couros and Novak, 2019) which they had used to guide their thinking and sharing with other teachers. The second teacher used the "Academic Mindset" framework (MindsetWorks, 2022) alongside the "Helping Children Succeed" book (Tough, 2016) to structure his teaching. Finally, the third teacher who taught from primary all the way up to the International Baccalaureate level mixed the International Baccalaureate MYP Design Cycle (IBMYP, 2022) with Stanford University's Design Thinking cycle (Stanford, 2022). Whilst these partly formulated the high-level goals teachers target in their use of the SAM Labs kit, they represent over-arching holistic approaches to teaching rather than concrete measurable dimensions easy to translate into data analysis and visualisations requirements.

When designing open-ended projects, teachers carefully select the project learning objectives to align as closely as possible to the various potential routes students might take to complete their projects. In doing this, teachers acknowledge the value of students formulating their own goals within the scope of the teachers' expected learning objectives, rather than simply following a prescribed set of tasks crafted by someone else entirely. This way, teachers provide agency for their students and help them take responsibility for their learning.

The frameworks guided not only the design but also the on-going support and evaluation of the project-based activities using the SAM Labs kit. The teachers used criteria rubrics which included the learning objectives the teachers were expecting students to showcase throughout the project. The learning objectives usually included a mixture of computational concepts as well as procedural behaviours such as using research to generate ideas and demonstrating an understanding of iterative design processes. Whilst the rubrics were usually designed to cover the students' activity throughout the whole project, the teachers would only fill them in at the end. This resulted in the evaluation criteria often being completed against the end-product the children produced. The teachers also noted the difficulty in assessing the procedural components of their evaluation criteria. Whilst the computational concepts would be more easily evaluated based on the form in which the students had applied them to their final designs, the procedural parts of their activity would be based on teachers' memory and impressions of the extent to which each student appeared to engage in a specific behaviour, such as the iterative design process. For example, whilst the teachers could explain their assessment of students' use of conditional cases in their SAM Labs circuits, they were less precise regarding how they would evaluate students' engagement in iterative design.

However, teachers are quick to acknowledge that an unfinished product that does not tick all the criteria does not necessarily mean those students have not learnt a lot during the project. Equally, a well-polished end artefact that scores well against the evaluation criteria may not be directly correlated to the biggest learning gains. Most often, the final project evaluation criteria described a well-designed artefact, which teachers highlight is not reflective of the students' learnings during the project. A student can get to the end of the project with a half-finished artefact, having gone through a high number of iterations, explored different parts of the kits' functionality in depth, and gone far out of their comfort zone testing a range of different hypotheses, all of which will have constituted opportunities to practice both their problem-solving skills as well as the constructs underpinning the kits' functionality. On the other hand, a different student can end up with an artefact which scored at the top end of the marking criteria, using mostly previous experiences with the kit they were already familiar with, exposing themselves little to new parts of functionality or new hypotheses to test which would take them outside the remit of what they already knew. This creates a fundamental issue for the evaluation of such projects based solely on the end-product.

In order to mitigate for such scenarios, the teachers looked for ways of integrating the process students take to arrive at their final artefacts into their assessment and support strategies. Teachers repeatedly emphasised the importance of students' argumentations of the ways in which they reached their decisions, over the resulting designs. In evaluating the projects, the teachers would try to understand the students' thinking processes that led to their constructions, often requiring students to write explanations or showcase the steps they took to implement certain behaviours. The importance of iterative design, experimentation and evolving designs are aspects of the learning experience teachers frequently came back to as more reflective of a students' performance than what they produced at the end. Teachers mentioned different methods of trying to expose their students' thinking process, by encouraging them to document the different stages they go through towards the completion, discuss the challenges they encounter and how they have overcome those, and sharing their progress with their peers. In this way, the teachers become more aware of all the ideas generated across the entire project, the strategies students used to test their hypotheses, as well as the way in which they would use feedback to inform future versions of their designs. Whilst the end-product may serve as a proxy for some of these aspects, teachers remain fully aware of its limitations in interpreting students' actions that ultimately lead to the generation of their constructions.

However, when asked about the type of data used to analyse their students' decision-making processes, or the specific characteristics they looked for in evaluating students' iterative behaviours, the teachers were not able to point to objective measures. Instead, they would subjectively estimate the extent to which they felt each student had achieved each learning objective, based on their own observations and the students' explanations throughout the project. This demonstrates a tension between what the teachers want their evaluations to be primarily based on, and the data and frameworks available to inform them.

In addition, teachers recognised the limited scope of the end-product evaluation criteria in helping them support their students' activity. An important aspect of the teachers' actions in scaffolding their students' activity is their interaction with the students. To support their students, the teachers would usually complement their understanding of a given situation with the students' explanation of where they are at and how they got there. Teachers seem to instinctively recognise that no matter the accuracy of their interpretation of any given situation a student finds themselves in at any point, this would require pairing with the students' interpretation of the same context. In this way, teachers build a bridge between what they think it might be useful for the students to do, and the students' justification and perspective on how they got to that point and what they were trying to achieve: "Jack, what's happening?". Using this information, the teachers proceed to offer questions or suggestions to help the student move forward. The students' side of the story, the thought process behind their actions which is not captured in their resulting outputs is what they teachers often build their interventions on.

4.1.3 Summary

The observations presented above form the basis of the educational problem this thesis aims to investigate: **SAM Labs designs evolve in relation to functionality goals through a series of iterations students often find difficult to document or articulate, leaving teachers with little information to assess the process students engaged in to arrive at a final design**. The specific ways in which students were observed to iterate through versions of the SAM Labs constructions are summarised below:

1. Having the tangible blocks helped the students practically apply the abstract constructs being explained to them, such as the circuits structure of input -> connection -> output, the functionality of each block and troubleshooting strategies.
2. The students' freedom to experiment on their own led to a high degree of customisation from each student, with students seeking for personalised ways of approaching the constructions.
3. The students were motivated to use their available lesson time to experiment with the blocks in ways that didn't subscribe to either the demonstrations of the SAM Labs representatives, nor the most efficient routes to building the set challenges. Instead, they were keen to verify their own assumptions of how the blocks might work, or pursue their own interpretations of the set construction challenges.
4. The students' invalid circuits would vary between wrong structure, wrong sequence, or wrong behaviour against expectations. No linear progression was observed between these different types of errors,

with most constructions entailing a series of all three types of error at different times across distinct designs.

5. The students appeared to apply a goal-oriented design, where they would identify either a behaviour or experimentation goal they would carry out through various iterations. Examples of where the students' behaviours appear either ineffective in relation to the set construction challenges, or invalid against the SAM Labs design rules, most often transpire to be intentional steps that students perceive as necessary towards their own goals. For example, when breaking the input -> connection -> output structure, despite repeatedly applying it successfully in previous constructions, the students would be testing a hypothesis of a circuit they believe should work. Or when actions seem to be randomly repeating themselves without a clear aim, the students try them over and over again to better understand the consistency of the outcome on the physical blocks.

4.2 Appropriation Model

The second section of this chapter aligns the observations captured in the authentic learning contexts presented in the first section with the theory of appropriation. In this section, a model is created which contextualises the students' iterative design activity in the process of appropriation, as defined earlier in Chapter 2. First, this section starts with a presentation of the open-ended features of the learning activity and the ways in which they support students' appropriation of the SAM Labs kit. Second, an appropriation model is shaped around one example student, representative of the behaviour observed across the entire student cohort.

4.2.1 Open-ended affordances

The SAM Labs activities underpinning this study were deliberately designed in an open-ended fashion to encourage students to engage in an ideation process and implement their own ideas within the project brief. There are three different ways through which the learning design practically supports an open-ended approach:

1. Firstly, the SAM Labs blocks themselves were designed specifically for users to be able to mix and match various inputs, connectors and outputs into their own circuits depending on what they want to achieve. The SAM Labs blocks are standalone individual physical components of similar size and shape, to be used free-standing or attached to analogue artefacts. For example, building a lights display can be made up of any number of LED lights, positioned in whatever shape necessary – a circle, square, or encasing a different object such as a display board or robotic moving box. The lights can be triggered manually on demand using a button, automatically using a variety of sensors, or using a timer. The designers' vision for the SAM Labs kit was for non-experts to be able to use electronic components in easy, flexible mix-and-match assemblies for art installations, early engineering prototypes or creative school projects, without a strict, prescriptive structure.

2. Secondly, the virtual SAM Labs canvas where users build their circuits was designed in a way that encourages free exploration and allows for almost any combination of blocks to be linked into circuits, provided the input -> connector -> output structure is followed. The canvas is completely empty, and users drag and drop their chosen SAM components which they then connect in whatever combinations they deem appropriate to achieve their purpose. This sometimes leads to inconsistent or flawed circuits, which the users can test and adapt, as necessary.

3. Thirdly, in the second research learning context, the teacher designed the project intentionally to be open-ended, with a brief which specifies the conceptual boundaries within which students have the freedom to design their own solutions. The students were tasked with designing a board game, with a historical theme, which must contain "intelligent" elements replacing more traditional, analogue ways of implementing game rules and mechanics. For example, designing a smart spinner using SAM Labs electronics rather than using a traditional dice. One of the main aspects which attracted the teacher to the SAM Labs kit was the open-ended design, on which she felt she could build on pedagogically with an open-ended project brief. The teacher was excited about the potential new ways in which students might think of using SAM Labs for the electronic board game elements she might have not

thought of herself.

The goal of designing technologies with "surfaces" that are left open for learners to appropriate for their own learning purposes is known as "designing for appropriation" (Tchounikine, 2017), "empowered design" (Marsden, 2008) or "interactional design" (Hook, 2008). The three open-ended characteristics provide students the opportunity to appropriate the SAM Labs kit functionality for their own purposes in the context of the project brief. Specifically, the construct of appropriation helps describe the outcome of the students' iterative design process they engage in to complete their SAM Labs artefacts. By iterating on their designs towards implementing their own goals, they appropriate the SAM Labs tool for their own purposes (Zamani and Pouloudi, 2019). Through each iteration, they expose their understanding of the kits' functionality as well as the procedural aspect of how they approach their constructions, resulting in the students' appropriation of the kit.

Appropriation affects the extent and nature of students' iterations (Zamani and Pouloudi, 2019). Section 4.1.1 highlights the ways in which students' choices in an open-ended context influence the type of experiments and goals that students subsequently actioned. The students' protective attitude towards their own ideas, regardless of feasibility, led students to their own individual iterative design paths, testing different ideas and different ways of constructing the same behaviours. Appropriation is used to highlight the distinction between the way in which students learn how to use a tool, depending on their distinct use of the tool to achieve their individual goals, made visible in their iterations.

The relationship between appropriation and iterative design is further explored in the next section. In the following section, a model of appropriation which situates the students' iterative design activity using SAM Labs in relation to their self-constructed goals is presented. We illustrate the model's manifestation in practice using examples from the second research learning context, where 12 Year 7 students build an "intelligent" board game over two semesters. Finally, we identify the implications such an appropriation model has for the ways in which trace data can exhibit the students' iterative design activity. Considering appropriation, we acknowledge the limitations of trace data to study the students' iterative design behaviours and explore to what extent data visualisations can support the teachers' reflection process to further expose aspects of the students' thinking that may not directly evident from the data. By incorporating the theory of appropriation into the research, the limitations of what information data can provide is highlighted and brought into discussion, as well as what it means for data visualisations to consider the idiosyncratic nature of knowledge acquisition.

4.2.2 Appropriation Model

In the process of implementing their own ideas, students practice their skills of formulating goals which fit the design brief, create plans to practically implement their goals, interpret the feedback of their tests and use this information to inform their next steps. This integration of the students' own goals and the iterative design activity is shown in Figure 4.1.

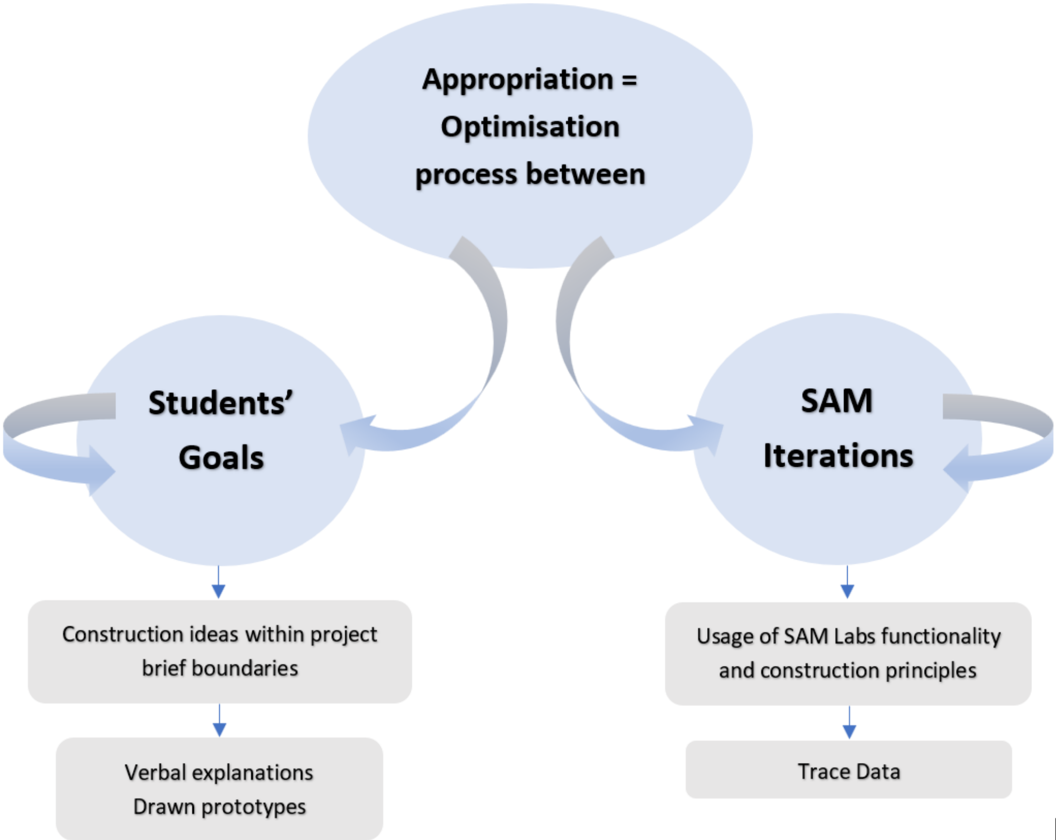


FIGURE 4.1: Appropriation Model

In the context of SAM Labs projects, appropriation is interpreted as the optimisation process of the students' self-made goals in relation to their iterative design activity, which are continuously adapted in relation to each other. The goals are formulated within the boundaries of the project brief, whilst the design evolves within the affordances of the physical computing kits' functionality. Within the current research study, the students' goals are externalised through the verbal explanations or drawings through which students express their intentions, while the evolution of their SAM Labs designs is captured in the trace logs.

The goals can originate from students' interests and experiences, knowledge of what is feasible to construct with the kits, or inspiration from external sources like their teacher or peers. The design is based on the students' existing knowledge of the tool's capabilities and hypotheses around what can be practically achieved with the kit. As the students test their hypotheses against their knowledge of the tools' capabilities, their understanding of the kits' construction principles gets refined in the context of their goals. The appropriation process entails a continuous optimisation of the students' intentions in relation to what is possible to achieve with the SAM Labs kit, and vice-versa, where they refine their designs in accordance with their specific intentions. Both the students' goals and their designs are two integral parts of the appropriation process which are continuously adapted and reformulated, individually and in relation to one another. This results in students constructing their own versions of knowledge and integrating it into pre-existing schemas. Further we will explore what this looks like practically in a few selected examples of students designing their board games.

The model acknowledges the students' active role in the learning experience and positions their activity as a goal-oriented, tool-mediated process of constructing their own knowledge (Grossman, Smagorinsky, and Valencia, 1999). This perspective is framed in activity theory (Kaptelinin and Nardi, 2006; Bødker and Klokmose, 2012), which offers an activity-centric perspective of how users use artefacts. Activity theory positions tools like SAM Labs as instruments for users to mobilize in the context of their activities, focused on the process in which students turn tools into means to achieve their goals, as amplifiers of thought (Rabardel and Bourmaud, 2003). This perspective represented in the appropriation model sits in direct contrast with a view which positions computing kits as tools to be used and mastered (Poizat, Haradji, and Adé, 2013).

Appropriation Model Example

We illustrate the appropriation model using one of the students who participated in the board game project. Six instances are highlighted where the optimisation process is showcased in the way the student negotiates between the desired game mechanics and the expected capabilities of the SAM Labs kit. The instances used in the example are summarised in Fig 4.2.

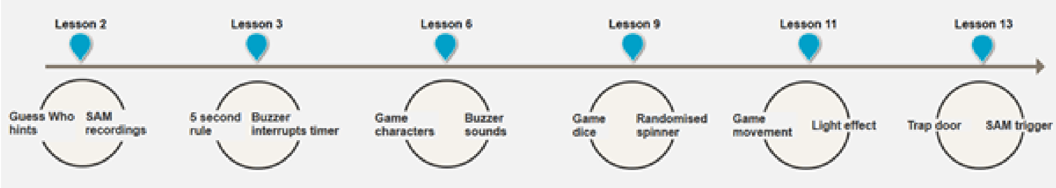


FIGURE 4.2: Appropriation Model Example

At the start of the project, in the first lesson, the student decides to create a "Guess Who"-type game, with picture cards that players must guess who they portray. One of the "intelligent" SAM Labs elements is planned as a hint request button, which, if pressed, plays a recorded hint about a given card. As they consider the practical construction of the hint behaviour during the second lesson, the student ponders: “I don’t know how I’ll do that. How will I actually do the hint? On a SAM? Although I might need a lot. Maybe I do it just for one, you’re only allowed one hint per Tudor." This refers to a main construction challenge: when the button is pressed, how will the SAM block know which exact hint, related to which card, to play? The student indicates he might have one button per card, each button being connected to a specific recording, for a specific card, however the student realises they "might need a lot". This generates a whole rethink of the game, the student re-orienting towards “a game like ‘The 5 second rule’, where you answer questions to move up on the board”. In line with the overall game type change, the student also rethinks their use of SAM blocks: “Using SAM, there will be a buzzer to buzz when you’re ready to answer the question, a timer to count down to 5 seconds, and the spinner.” This first optimisation example takes place at a high level, between the overall game design, and the hypothetical SAM Labs behaviours which might be feasible to implement in line with the nature of the game. In this case, the student reformulates their game to be more compatible with their high-level knowledge of what can be achieved with the SAM Labs kit. Their goal is adapted in line with their expectations of what is possible to achieve.

During the third lesson, the student starts considering the exact construction of the buzzer: “So what happens to the time when the buzzer goes?” When the teacher enquires about the buzzer’s construction: “So how is it going to work? Each person will have their own buzzers?”, the student gives an uncertain answer: ““So when you press the buzzer the timer stops… or maybe you just buzz before it goes off”. This time, the student sticks to the new game type, and display some comfort with pursuing a goal where they are not certain about the exact construction.

It is not until the 6th lesson that the student starts practically implementing their SAM behaviours. They go through a cycle of realising they don’t have a clear idea of where to start, and encouraging themselves to try things out: “How am I supposed to start SAM?”, “What blocks do we need to use?”, “I have no idea what to build..”, interlaced by “OK… so what is this?” “OMG this is a light sensor. OK ..how do I get rid of it..?”, “I’m not stupid. How do I do it?” and “Now I’ve got it” as they start experimenting. Eventually, as the student progresses through more iterations of the buzzer, they start negotiating the emerging design functionality with the game structure: “I’ll drop the Shakespeare <character>, I have 3 players”. The practical experiments help the student answer their own questions and advance their construction of the buzzer, narrowing the gap between a hypothetical goal and the concrete SAM design.

During the 9th lesson, after becoming more confident in their experimentation with the SAM blocks, the student starts displaying increased enthusiasm “I’m going to stick to SAM today”, working on their randomised spinner. At the beginning of lesson nine they had already built a version of a spinner, however the initial construction generates the additional target goal of making it spin in a randomised fashion, with the players not being able to easily guess how many moves they will make on the board. The initial design inspires a refinement to the goal, which in turn leads to various attempts at implementing the randomised behaviour: “Oh wait, OMG this is going to be the best randomiser… I’m going to put a delay in it.”

Until the 9th lesson, the SAM Labs iterations targeted specific behaviours the student wanted to integrate in their game. The goals were formulated, and the SAM designs followed. During the 11th lesson however, this dynamic is swapped, with the student implementing a lights system using a sensor without a concrete idea of how it will be integrated on the game board. When a peer asks “OH.. Wait, so what does that mean, when it flashes?”, the student starts laughing: “Then ahm…. I don’t know hahahahah the light flashes”. Eventually, they devise a goal to match a SAM design: “depending on what colour goes off, you can move forward or backwards”.

The game mechanics are revised in line with new-found SAM functionality the student is keen to incorporate.

During one of the last lessons, the student continues to integrate more SAM Labs behaviours, despite being one of the games in the class with most "intelligent" mechanics. The optimisation of goals against functionality continues. When one of the SAM representatives suggests a slight change to their randomised spinner “You could change the weighting of each probability, so that it’s harder or easier to get one of the higher numbers”.. but the student rejects it: “Not really. . . ”. However, when implementing the trapdoor trigger, the teacher suggests using a pressure pad instead of a button to make it more automatic. The student is open to the suggestion, making it their own: “Can I use a proximity for that..?”.

Each of the decisions above could have taken a different course, at each step. From the beginning, the student could have kept the "Guess Who" game idea, and explored other ways of implementing their hints, or explored other type of SAM behaviours to replace the hints system. Each decision is made at different stages during the project, influenced by the level of commitment invested in each idea up to that point, the evidence available to know whether a certain design might be feasible or not, or the level of comfort with trying out designs they don’t have a clear idea on how to implement from the start. Had the student optimised their decisions in different ways, either refining their designs more to match original intentions, or adapt goals to better match the SAM Labs functionality, the final game could have potentially looked very different. However, it is unclear whether any of the decisions can be considered "good", "bad", "effective" or "ineffective" if the student found a way to adapt considering the information available to them at any given point in time. These examples showcase the intimate relationship between the students’ iterative activity and their goals, showing that one cannot be analysed in isolation from the other.

Examples like the one above can be found for all students who participated in the board game. The qualitative data from the audio trail and the students’ digital journals allows us to review the optimisation process represented in the appropriation model at a macro level in students’ decision-making processes. We hypothesise that there is a much higher volume of similar decisions being made at a micro level with every single iteration in the SAM designs, which we aim to expose through our data visualisations.

Functional value

It is pertinent at this point to mention the notion of "functional value", in order to explain how the functionality provided by the physical computing kit intertwines with the users' perceived use (Tchounikine, 2017). The functional value of an artefact is defined as its utility to achieve some task or goal as perceived by the user (Tchounikine, 2017). An artefact cannot have a functional value on its own, but it is the user who attributes this as they perceive a use for the artefact. This perspective extends the optimisation process described in our discussion of the appropriation model above, between the tasks the users consider and the purpose for which artefacts are designed. Three types of functional value can be observed through the goals that students formulate when using the SAM Labs kit:

1. Out-of-bounds goals – a category of functions that are largely impossible to achieve given the kit's functionality. A few examples of such out-of-bounds goals are: creating a SAM Labs Monopoly money system, a lights system which automatically identifies correct or incorrect answers, or a vibrating dice, which the harder it is shaken, the longer it vibrates for and allows players to move their pieces forward. These go beyond the possibilities of what can be implemented using solely SAM Labs functionality. In all cases, the students renounced these ideas, replacing them entirely.

2. Functionality-related goals – this category constitutes most of the perceived uses students came up with to implement with the SAM Labs kit. These are mostly feasible goals, where refinements to both the goals and the designs are partly required, with an optimal solution achieved at the end of an iterative process. Students' perceived uses are largely based on the way in which the SAM Labs kit are designed to work, which are adapted in the context of the project brief driven by the students' interests and motivations.

3. Context-driven goals – functions which are outside the remit of the SAM Labs components' design, conceived by the users to fit specific goals. For example, using multiple routes between a single input/output route as a way of generating a random effect. This is against one of the underlying construction principles underpinning the SAM kit, which requires that any two input and output blocks are only ever joined up by a single possible circuit between them, regardless of how many

connectors are implemented in-between. However, by constructing multiple routes, the students achieved a random effect they had a specific use for in their random dice game behaviour. Students perceive and achieve goals based on designs which the SAM Labs kit was not originally designed for.

4.2.3 Implications for data analysis and visualisation design

The model of appropriation presented above allows for the formulation of data visualisation design goals, in acknowledgment of students' intentions which drive their actions but are not visible in the trace data:

1. **Build visualisations which convey aspects of the iterative design process independent of end-product**
   The open-ended aspect of the code clubs observed played an important part in the students' behaviours and the goals they formed as they worked with the SAM Labs kit. Instead of aiming for specific constructions, they were at liberty to produce they own interpretation of the challenge brief. The visualisations are aimed at open-ended SAM Labs design projects, as a means of encouraging the potential for students to engage in iterative design behaviours pursuing their own construction goals. Rather than looking for successful experimentation behaviours from a singular mastery-related perspective, or effective patterns targeting a single type of successful outcome, we embrace the variety of dimensions at play during SAM Labs projects, as well as the diversity of end-products which emerge at the end. Our visualisations' goal is to improve teachers' ability to better enquire into the students' thinking process, in a way that strengthens the support they can offer without restricting or inhibiting students' autonomy over their own task.

2. **Design visualisations which account for the iterative design process over the long term**
   For the code club students who had never used the SAM Labs kit before, a large amount of their SAM Labs activity was related to their understanding of the way in which the blocks worked, in relation to their goals. In other words, they focused more on how the kits worked in the first place, rather than how they might get them to do what they wanted them to. As the code clubs progressed, the focus shifted increasingly towards manipulating known functionality in ways that could result in specific constructions. Building on the differentiation

Werstch makes between mastery and appropriation (Wertsch, 1991), here too, a differentiation is observed between students testing to learn how the kits worked in comparison to testing towards a specific design using already existent functionality knowledge. Whilst a clear separation cannot be made between the two, this distinction is catered for by using a long-term project as the principal data collection and analysis context, following the project across several weeks' lessons, rather than singular one-hour sessions. In addition, the project was based in a school with existing SAM Labs experience, rather than introducing SAM Labs as a new tool in a new school. This enabled two things. Firstly, the learning experience design was led by the teacher themselves rather than a SAM Labs expert, capturing the perspective of a teacher's view of SAM's pedagogical value, rather than as intended by the SAM Labs designers. Second, the learning objectives focused on the use of SAM Labs once the students and teachers already know their basic functionality, rather than capturing the initial learning curve of the block functions and circuit construction structure. Therefore, the data analysis will converge around the iterative design of specific SAM Labs behaviours rather than the students learning about the SAM Labs kit itself. Finally, the visualisations were evaluated with teachers who already knew and worked with the SAM Labs kit. Feedback was gathered from teachers who already went through a period of thinking about the SAM Labs' kit pedagogical value as well as ways of integrating it into their teaching and evaluating students. Therefore, the evaluation was focused on the extent to which the visualisations align with the teachers' existing experience of SAM Labs.

3. **Position the visualisations as a reflection tool**
   An important aspect of the teachers' actions in scaffolding their students' activity is their interaction with the students prior to intervention. Regardless of the level or amount of information teachers have available to them in terms of understanding the context and the problem the student is trying to solve, during the lessons and code clubs the teachers would usually complement their understanding with the students' explanation of where they are at, how they got there and why. Teachers instinctively recognise that no matter the accuracy of their interpretation of any given situation a student finds themselves in at any point, this requires pairing with the students' interpretation

of the same context. In this way, teachers build a bridge between what they think might be useful for the students to do, and the students' justification and perspective on how they got to that point and what they were trying to achieve: "Jack, what's happening?". The students' side of the story, the thought process behind their actions which is not captured in their end-products, is what the teachers often build their interventions on. The visualisations are intended as helpful reflection tools for teachers rather than student performance trackers. Accounting for the "invisible" thought processes occurring during students' engagement with the SAM Labs tool, including their intentions as they iterate between versions in their constructions, the data visualisations are designed with the aim to surface questions about the students' decision-making process. The data visualisations are intended to help teachers' awareness of students' actions and elicit their thinking processes. Targeted at practitioners as objects to think with, they will be designed to provide more concrete ways of discussing different aspects of students' engagement with physical computing kits.

4.2.4 Summary

We use the appropriation model and implications presented above to guide the data visualisation design process and frame the interpretation of the data gathered for the student cohort who participated in the Keble School intelligent board game project. In creating the appropriation model, we propose a holistic interpretation of the learning experience, exploring both what trace log data can expose about the students' iterative behaviours, as well as what it cannot. The data visualisations are positioned as complementary tools for teachers to gain further insight into the students' iterative design behaviour. The information in the trace logs can also be used to uncover aspects of the students' learning experience which cannot be reliably tracked, allowing teachers to generate questions that are relevant for students' own reflection. Finally, the visualisations are evaluated according to the extent to which teachers can use them as stepping-stones to investigate students' iterative design processes in a way that preserves students' autonomy over their own design task and goals.

Chapter 5

Data Visualisations Design

This chapter presents the steps taken in arriving at visual proxies for exploring aspects of students' iterative design process, as they emerge from the practical learning context, in alignment with appropriation theory. This chapter represents the first research phase of the thesis, aimed at answering the first research question of "How can trace data be used to visualise the evolution of students' SAM Labs designs?". This chapter identifies visual proxies prototyped to quantitatively explore aspects of the iterative design behaviours students engage in. A quantitative ethnography approach (Shaffer, 2017) was used to establish a suitable language to quantitatively describe aspects of the students' iterative design process, aligned with the outcomes from Chapter 4. The visualisations are positioned as vehicles to describe the flow of changes between consecutive versions of the students' designs across time and explore students' iterative actions.

Given the little research done to quantitatively analyse students' iterative design behaviours and the goal of the present research to explore the construct with teachers in real-world contexts, we place data visualisations as a suitable mechanism with which to better understand how the iterative design process unfolds in contexts where students learn using physical computing kits. Data visualisations are positioned as 'objects-to-think-with' for teachers to reflect on the students' iterative behaviours and inform the further operationalisation of the iterative design process in quantitative terms for further research. In the context of the present research, we align with the wider data visualisation goal of empowering decision-makers with increased evidence rather than automating any aspect of the feedback or evaluation process (Bederson and Shneiderman, 2003). Furthermore, the use of data visualisations to offer teachers increased information on the students' behaviours also aligns with the appropriation argument, which emphasises the idiosyncrasy between students, difficult to standardise across large cohorts especially in constructivist, open-ended learning experiences.

5.1 Data Visualisations

This chapter presents the visual proxies prototyped to quantitatively explore aspects of the iterative design behaviours students engage in. First, we describe the learning design of the Keble board game project and identify the pedagogical elements related to the iterative design process. We identify the core elements of learning design: the learning outcomes, learning tasks or activities, learning resources and support mechanisms related to iterative design (Bennett, Lockyer, and Agostinho, 2018; Law and Liang, 2020). We then describe the data and use quantitative ethnography to provide the domain vocabulary of the data analysis (Hernández-Leo et al., 2019), and the interpretive pedagogical grounding to guide the data collection and evaluation, to ensure the visualisations are appropriate for the given context (Macfadyen, Lockyer, and Rienties, 2020). This way, the visual proxies complement the learning design decisions supporting the iterative design process as they apply to the authentic learning context. Finally, the visualisation prototypes are presented alongside the way in which they are designed to support the reflection process.

5.1.1 Iterative Design Process Learning Objective

We describe the practical ways in which the students' iterative design process was incorporated into the learning design, reflected in the tasks the students engaged in throughout the project's lessons.

The teacher designed the board game project as a continuation from the previous year's one-hour lessons with the SAM Labs kit. The individual lessons were contained, short computing activities which focused on individual computational constructs, focused on getting the students familiar with the kit functionality and main construction principles. As a continuation of the skills worked on in the previous year, the board game project was designed to give students the opportunity to apply what they knew already about SAM Labs in a new context. The teacher hoped that a long-term project would encourage students to generate new ideas of using the SAM Labs kit and have the time to iterate through possible constructions towards their final constructions, rather than following prescribed steps towards specific constructions. In addition to the previous year, the board game open-ended project offered the students the opportunities to generate their own ideas of what is possible to build and follow their own ideas through various iterations until a final artefact is produced. Through the board game project, the teacher targeted both the confidence and planning required for students to articulate their own ideas and take them to completion. The teacher identified several aspects she expected at least some students would find challenging relating to their iterative behaviours, given that this was the first project of this long-term, open-ended nature they engaged in:

1. Identify and articulate their own ideas of SAM Labs behaviours
2. Use feedback from intermediate designs to adapt accordingly
3. See their designs through to completion, identify flaws in their constructions and find solutions that lead to a complete and workable artefact
4. Document and explain design iterations

All three aspects underpin the "Understanding of the Iterative Design Process" learning objective set by the teacher, as presented in Chapter3. The teacher positioned them as both challenges and opportunities for their students, acknowledging that simply offering students opportunities to exercise iterative design skills does not automatically lead to improvements. The teacher hypothesised that the main challenge for her students would be to “think for themselves, go outside the boundaries, not just the obvious, try things out, experiment”. In that vein, she was hopeful that the long-term, open-ended nature of the project would encourage students not to be “scared of adapting their ideas and approach, afraid of change. It doesn't matter just about the end product" (Teacher I).

Activities to support the iterative design process

Part of the "Understanding of the Iterative Design Process" learning objective, the teacher designed ways of scaffolding of students' iterative design process throughout each lesson. The students used the See-Saw platform digital journals to upload their work each week in the form of photos, videos or written posts. The teacher used See-Saw as a way to encourage feedback between peers outside the classroom, prompting the students at regular intervals to log their progress and comment on each other's work. The SeeSaw journal was also used as a reflection tool for the individual students to view their own progress throughout the semester and reflect on the changes they've made.

Each lesson, the teacher tried to incorporate activities, with reflection or journal tasks that would encourage specific ways of engaging with the learning objectives. In the first lesson, when first presented with the idea of changing their design based on feedback, the students responded with a sense of disbelief and even amusement. When the teacher explained her expectations: "You are going to need to keep flexible throughout the stages of the game. We are going to keep going back and change things. What you have got now, do not be afraid to change those ideas when you get your feedback", the children lightly chuckled in the background at the idea of any significant change being acceptable.

In the third lesson, the teacher dedicated part of the lesson for each student to video-record their ideas and share these with their peers on SeeSaw. She also set aside time for each student to watch their peers' ideas and provide constructive feedback to each other. Finally, she encouraged students to document any changes that might have resulted from the feedback received from their peers: "Feedback on each other's Explain Everything Design Specification videos in SeeSaw. Did you change your design specification and idea after feedback? If so, what did you change? Why?"

During the fourth lesson, the teacher emphasised the iterative process students might engage in based on their initial sketches of their SAM Labs designs, following the prototyping process and peer feedback: "**Activity**: Sketch out your ideas as best you can. Once sketched out, try to design in SAM. You may have to adapt your ideas. After feedback and possible adaption of the ideas, upload final designs to SeeSaw" + "**Reflection**: Give students opportunity to get other people from the class to look at their design and comment on it. After the feedback, give the pupils time to adapt their board design if necessary. **Journal task**: Did you change your ideas during the design process?"

In the fifth lesson, the teacher focused on the possible challenges the students encountered during their SAM Labs design process, and asked the students to specifically emphasise these in their journals: "**Activity**: Research and brainstorm ideas using Sam to design a way for the players to move around the board. You have the freedom to test out your ideas with your board design and get feedback either directly from others testing or by posting your ideas on Seesaw. You need to take images of the different stages of your ideas, both of the Sam canvas and the moving model, even if you decide against your idea. **Reflection**: What went right or wrong, and how did you solve the problems? Does it help to see others' planning? Did you go back and improve or change your planning after getting feedback? **Journal task**: Have you learned how to use the software blocks in a new way to create your solution? Did planning your means of moving your player, getting feedback, adapting your ideas help you refine your idea?"

The teacher repeatedly emphasised to the students the iterative nature of the project and tried to communicate the positive aspects of students changing their designs along the way: "It's great to see all the different ideas. It is also great to see how you are changing these as you go along. I would like to see the ones you started with, as well as those that are now coming together, so do not upload just the current ones, upload all your previous ideas. It will be very interesting to see how you evolve. Whatever you are thinking now, it will keep getting refined and refined and refined". At different points throughout the project, the teacher would re-iterate the same ideas in different ways, worried that students were inhibited to show their work-in-progress to avoid scrutiny from their peers, or perhaps early judgments or ideas that weren't fully developed: "This was just getting some ideas together of how it may end up and what might be possible. You are going to develop this week after week, and you are going to have time to modify it all along. Keep changing those ideas, revising those ideas, testing those ideas. You might come out with something completely different than you started with. This was about getting you thinking and started. This is not going to be how it's going to end up." Especially, the teacher tried to frame the students' changes in a positive light and position them as signs of productive engagement with the project, rather than anything to avoid or be afraid to share. This was something the teacher was particularly conscious of, in the knowledge that it was a distinctly different attitude to what the students were accustomed to: "At the end when we look at the final projects, look back on what you each started with. Will it be anything like what you produce at the end? Did you change things dramatically along the journey?"

5.1.2 Trace log data

At a basic level, when using SAM, students experiment with the effects of building different circuitry using the physical blocks. Children formulate hypotheses which are translated into circuits, they interpret the feedback of the tests and formulate new tests, in an iterative, actionable cycle. These tests are captured in the log data, which can be used to describe the students' actions in ways that address learning-related questions. Using the changes between versions as the unit of analysis, we track the changes the students make between blocks, edges and whole circuits – the components of SAM Labs designs. We map these to relevant questions descriptive of the iterative design process as it emerged from the theoretical and observational stages of the research, in a bid to create a mapping between the learning design and learning analytics.

Changes as unit of analysis

To represent the students' iterative design process, each state of the SAM Labs virtual construction is considered an intermediate version leading to the student's final construction. The changes between the states are used as a way of recording the progression between iterations.

Examples from literature, as presented in Chapter 2, where incremental changes are used as units of analysis to build representations of students' construction paths in open-ended coding assignments are built upon. Yan et al.'s visual tool that organises snapshots of students' code as they progress through the assignment (Yan, Hu, and Piech, 2019), alongside the design principles of the Replay tool (Tseng, Hemsley, and Resnick, 2012), and Ben Fry's text evolution visualisation (Fry, 2008), serve as guiding examples on how to approach the analysis of the trace data. Every version is considered a legitimate work-in-progress version that is representative of the students' thinking at a given point in time, to be inquired into and built upon. In addition, the students' iterative design process is treated as a continuous refinement process rather than a set of steps with an end point from which to judge the changes by.

SAM Labs changes

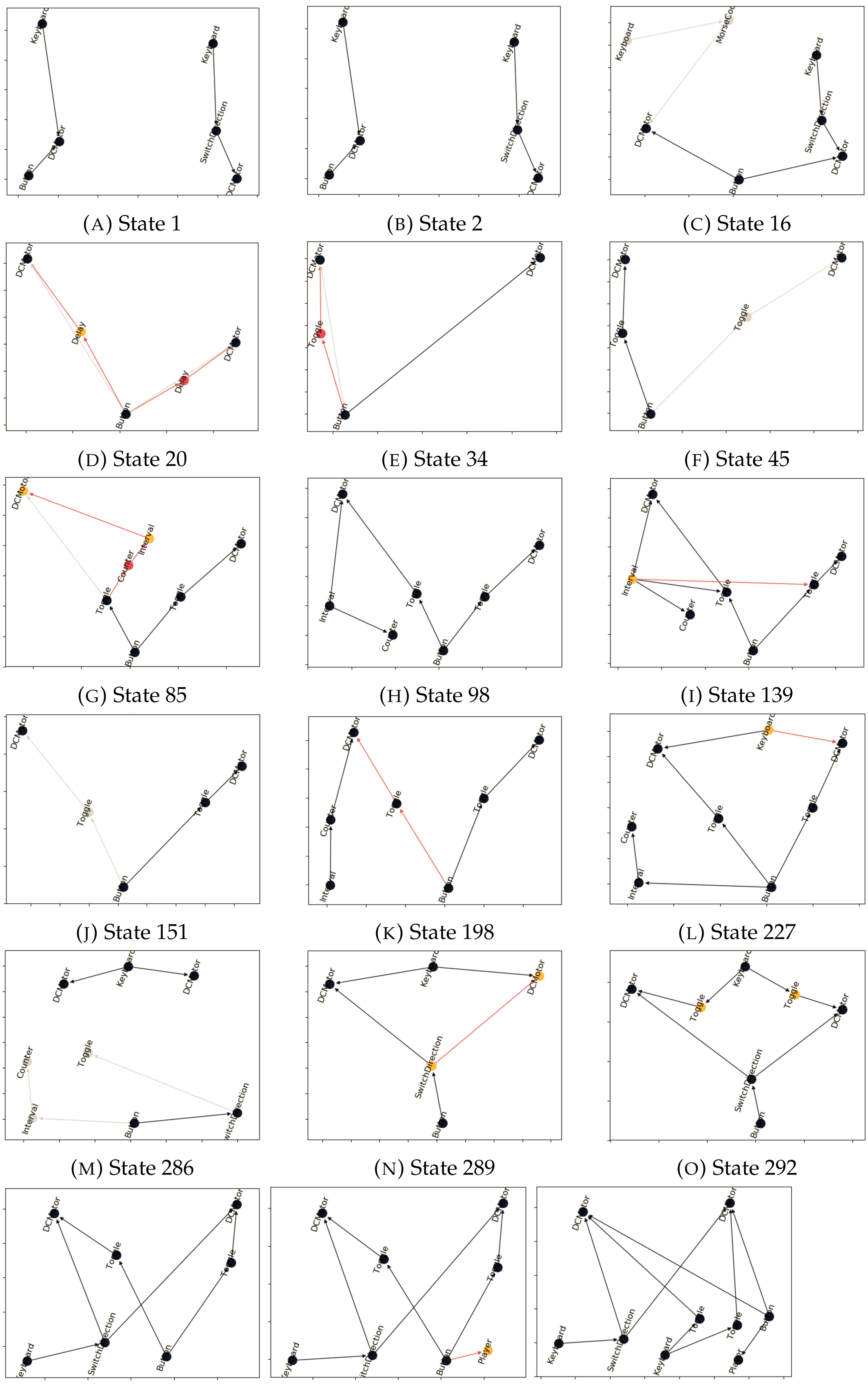
The trace data was collected specifically for the present study, by the SAM Labs software development team, at the researcher's request. Beforehand, the students' designs would be overwritten with the latest changes, with no record of previous activity saved. To study the students' designs' evolution, a history of the students' changes needed to be preserved.

In an initial investigatory step, the trace data was visualised in its low-level format, as it was saved in the trace data logs, with no further manipulation. This initial visual examination of the trace data formed part of the data manipulation stage, before any teacher-facing visualisations were produced. The changes between states were produced in this way for all students. These are accessible at this Dropbox location: https://www.dropbox.com/sh/j3hepeyuhjsyh72/AABKP-XVeWDVtYLFXuvu7xQLa?dl=0.

Below, we exemplify what the trace data looks like for one SAM Labs construction from a single student, and the type of information that can be obtained. These were used by the researcher to better understand the data available to work with, and the type of changes occurring between versions.

In Figure 5.1, the nodes represent SAM Labs **blocks** and the lines represent **connections** between the blocks. Each distinct path from an input to an output represents a **circuit**, and the totality of the circuits makes up the whole construction **design**. The states are intermediate versions of the final construction design. Each **state** is displayed in relation to its previous, with new blocks or connections shown in red, modified elements shown in yellow, removed elements in grey, and all other unchanged elements black. Each circuit will typically be dedicated to implementing a specific **behaviour**, with a project typically containing multiple behaviours. For example, a car design might include a couple of distinct behaviours: the wheels powered by the motors and a front light using an RGBLED, each powered by separate inputs. Each of these behaviours would be implemented in a separate circuit.

Figure 5.1 shows a subset of 18 out of 346 states recorded during the construction of a car by a single student during one of the code club sessions. The states progress from left to right on each row, from top to bottom. The full 346 states represent the entirety of the student's actions in constructing their car, as a result of their thinking process. Whilst these are not intended for the teachers to be reviewed directly, they constitute the basis for the visualisations. Reviewing the changes as they occurred throughout the whole project without interpretation offered insights into what may constitute useful information to be further disseminated and visualised summatively in the data visualisations.



(A) State 1 (B) State 2 (C) State 16

(D) State 20 (E) State 34 (F) State 45

(G) State 85 (H) State 98 (I) State 139

(J) State 151 (K) State 198 (L) State 227

(M) State 286 (N) State 289 (O) State 292

(P) State 325 (Q) State 332 (R) State 346 (Final Design)

FIGURE 5.1: A subset of 18 iterations reflecting the changes carried out by one student when creating their electronic car. New blocks or connections shown in red, modified elements shown in yellow, removed elements in grey, and all other unchanged elements black.

The subset presented in Figure 5.1 constitutes a practical explanation of how the SAM blocks work, for the reader to better understand their functionality, and are the basis of the visualisations presented further in this paper. The states represent the student's working-out of the final graph, with all the steps building up to the end version. In this format, insights are difficult to derive, and require a manual, time-consuming analysis of each state in comparison to its previous. However, they do prompt specific questions around the students' construction process, in relation to the design goals identified in the previous chapter:

- What blocks do the students consider appropriate to use and construct their target behaviours with?
- What iterations make up the evolution of the SAM Labs design?
- What proportion of the students' iterations contribute directly to the final design?

In Figure 5.1, the project brief was to build a car which can go forwards, backwards, left, right, stop and start, as well as adding any further customisations the students see fit, such as warning sounds or lights. A button and two keys are used to trigger a change in behaviour on the motors. If the button makes the motors start, one of the keys can trigger the car to turn left, another to turn right, and so on.

In State 5.1c, it can be observed that the student experiments with adding a MorseCode block into the circuit – an invalid move which would have stopped the motor from being activated, as well as later trying out the Delay, Counter or Interval blocks in State 5.1d, State 5.1g - State 5.1i, State 5.1k - State 5.1o, all of which are temporarily tested and removed. Some are used incorrectly and would have produced an interruption in the circuit functionality, yet some are valid and in alignment with the way in which the blocks were designed to operate. Yet, there are many occasions where SAM valid circuits are modified and broken again, as they do not align with the student's intentions or expectations.

Some blocks are used more consistently throughout, such as the button and keyboard inputs, the two motors outputs as wheels, and a set of connecting blocks such as the SwitchDirection, or the Toggle which turns the motor on or off. The student iterates through various connections between these more consistent blocks, arriving at a final state which would produce a car able to go forwards and backwards as well as stopping and starting. The student also goes through different states of simplification, at times removing most of the blocks on the canvas to rebuild from known circuits which work as expected, to continue experimenting with new blocks or new connections which they are yet unsure of the outcomes.

The changes are an expression of the students' understanding of how the SAM blocks work, and the resulting iterations represent modifications in relation to what they are trying to achieve. The students are observed using blocks they never saw demonstrated, nor tried before themselves. These attempts communicate the students' beliefs about how a component might work in relation to the purpose of their construction. These constitute opportunities for students to try out their hypotheses for themselves, and where applicable, to generate questions about the block's functionality and new hypotheses around how it may be applied elsewhere. Finding ways of combining all 346 states in consolidated views would allow for an observation of the flow of changes as they occur over the project timeline, offering a holistic representation of the iterative design process.

Using the changes between consecutive states of the SAM Labs designs as the unit of analysis for the visualisations of progress, every change is considered informative. Each change is considered to serve some purpose for the students, as observed in the code clubs, and instructive about the students' personal understanding. The visualisations are positioned as vehicles to describe the changes and help further elucidate the students' thinking and decision-making process.

Changes over time

We use the quantitative ethnography methodology to split up the trace log data across time into meaningful chunks. Shaffer introduces the quantitative ethnography methodology (Shaffer, 2017) as a means of focusing on understanding "what data means to the people who are studied". Shaffer applies grounded theory to Big Data in order to add meaning to the data analysis, as a means of exploring what people do and why (Shaffer, 2017). By merging Big Data with ethnography, the focus shifts towards the process: how and why things happen, rather than remaining solely concerned with distinct correlations between variables. Shaffer uses the ethnographical perspective of identifying how people make decisions, rather than verifying whether those choices are widely held (Shaffer, 2017). Following the same rationale, we look for ways of breaking up the log data in ways that apply to the individual and can be used to further explain their actions, rather than seeking for patterns across groups of students from isolated dimensions. A language is needed to make sense of the data and describe the nature of the experimentation process (Shaffer, 2017). Segmenting the data requires splitting it into meaningful parts, by identifying the units of analysis and their relationships to one another. We follow Shaffer's line, conversation and stanza model to split the log data across time.

Construction sequences are identified in the flow of individual states making up the students' SAM designs and mapped to the quantitative ethnography elements, as shown in Figure 5.2 and expanded below:

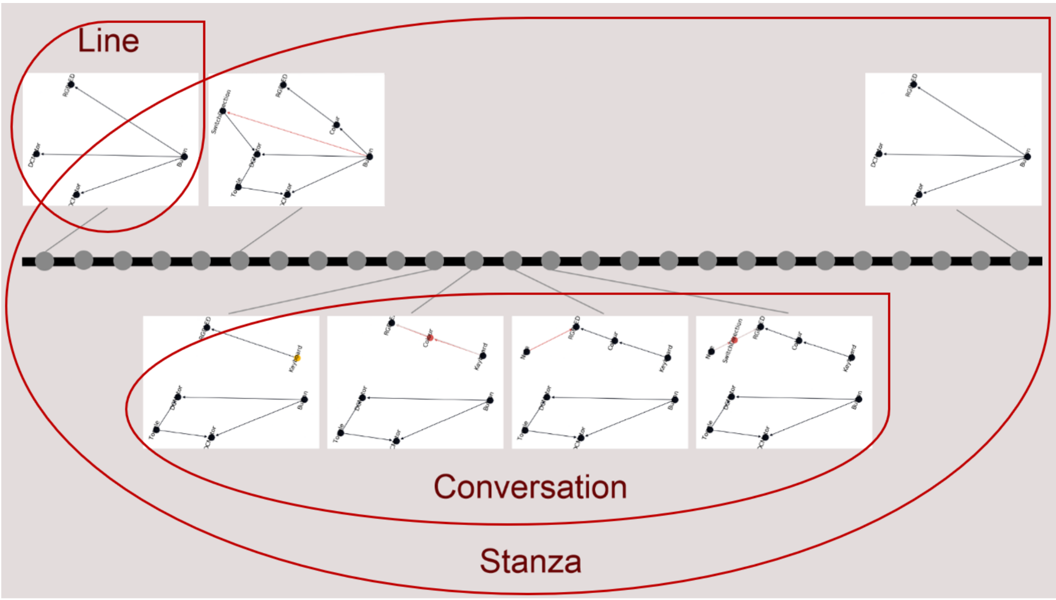
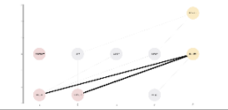
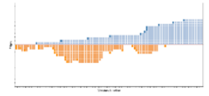


FIGURE 5.2: The quantitative ethnography elements of line, conversation and stanza in relation to the SAM Labs trace data as encircled by the red lines

- **Line**: the smallest unit of meaning considered in the analysis. Each version stored in the logs is treated as a line. Each version represents an instantiation of each step the students take towards constructing their designs
- **Conversation**: set of lines that can be related to one another. All the lines which contribute to the construction of a specific SAM Labs behaviour can be grouped together, as the steps taken towards building an individual piece of functionality of the overall design. The multiple iterations of adding, removing or replacing blocks and connections in the context of a single circuit is considered to follow a single trail of

TABLE 5.1: Data Visualisations Summary

	Blocks and Connections 	**Blocks across Contexts** 	**Distinct Approaches** 	**Kept versus Discarded** 
Core information	- blocks - connections - usage distribution of blocks & connections	- blocks - connections - belonging circuits - usage distribution across circuits using the same block(s)	- distinct design approaches - time spent iterating on each approach - validity of approaches	- volume of kept / discarded connections - timing of kept / discarded connections - validity of kept / discarded connections
Inquiry points into nature of iterations	- suitability of blocks in relation to the construction task - connections which got worked on more than others at which level	- validity of the blocks' usage - similarity between circuits using the same block(s) - suitability of circuits in relation to the construction task - circuits which got worked on more than others	- similarity between approaches - ways in which approaches build upon each other - suitability of intermediary designs in relation to the construction task	- amount of time spent on discarded work versus amount of time dedicated to final design across the available project period - number of connections considered unsuitable for the final design - number of discarded connections due to invalidity or valid but inadequate behaviour

thought towards a single piece of functionality within the whole SAM design

- **Stanza**: set of lines in a single conversation that are within the same relevant context, therefore related to one another. From the SAM logs, these constitute the totality of behaviours connected together from multiple circuits into a single design. The conversations come together within the context of a single project

5.1.3 Data visualisations

For the design of the data visualisations, change as the main unit of analysis is applied to the trace data across time to provide a narrative of the students' iterative design behaviours. The way in which the block, connection and circuit elements change across lines, conversations and stanzas is visualised in different formats. These are summarised in Table 5.1, alongside the core information each visualisation contains and the inquiry points each visualisations aims to offer.

An explanation of each visualisation is expanded below, accompanied by a discussion of the ways in which they might inform the students' behaviours and support guided reflection. These are explained within the context of a car construction activity, using examples from multiple students.

Blocks and connections

The 'Blocks and Connections' visualisation aims to show all the SAM Labs blocks and connections worked with by the students across a stanza, throughout the whole project. A first example is shown in Figure 5.3. The visualisation is a 2D graph, where the nodes represent the SAM Labs blocks and the edges are the connections between the blocks. The red nodes indicate input blocks, blue nodes indicate connector blocks and yellow nodes indicate output blocks. The width of the lines is representative of the number of lines the connection appears in across the stanza.

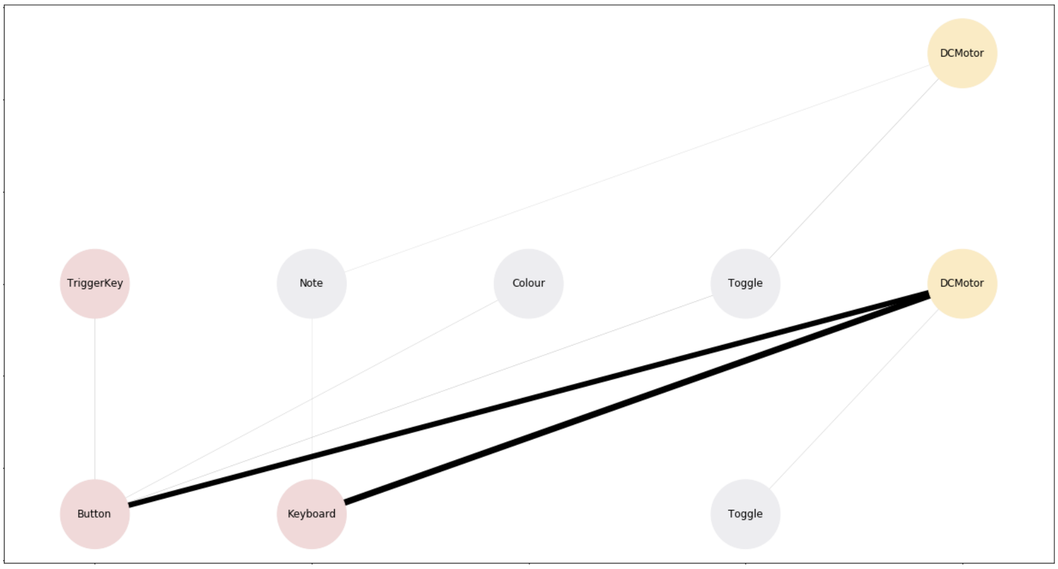


FIGURE 5.3: Blocks and Connections example 1; displays all the blocks and connections used in a car construction project; red nodes as input blocks, blue nodes as connector blocks and yellow nodes as output blocks; thickness represents how many times the same connection is used across the project timeline

In Figure 5.3, whilst building their car, the student predominantly uses the Button and Keyboard inputs to activate the Motors directly. They briefly add the TriggerKey, Note, Colour and Toggle connectors to their circuit, without spending very long experimenting with either.

Figure 5.4 showcases the same student's second attempt at building a car, across two separate code clubs. It can be noticed that in their second attempt, whilst maintaining the Keyboard and Button direct triggers of the Motors, they also experiment with the SwitchDirection block which is used appropriately in between the input and the motor, as well as introducing the RGB LED and Player for sounds and lights in their design. An evolution can be observed between the two instances of the same visualisation from the

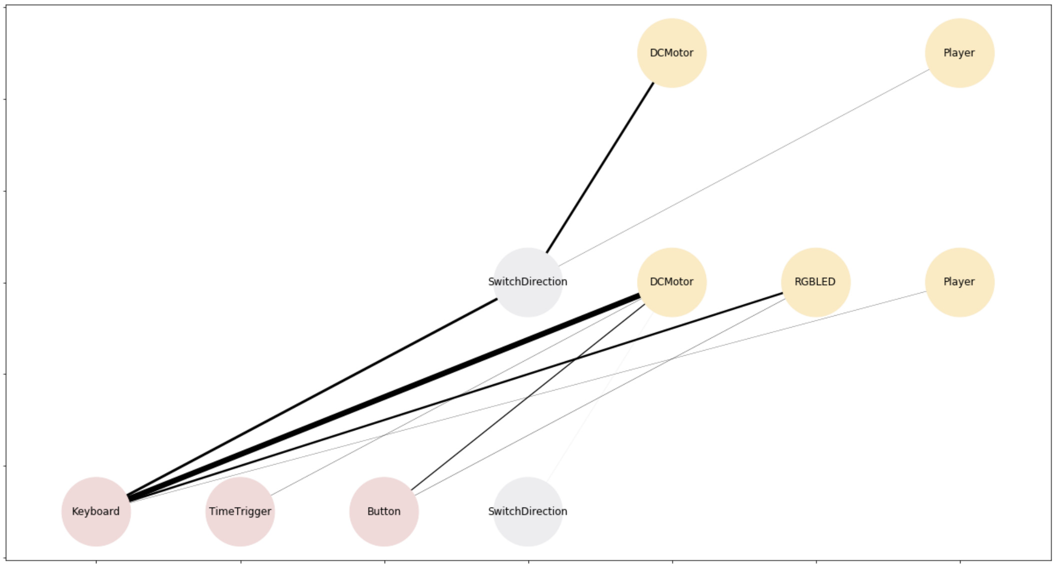


FIGURE 5.4: Blocks and Connections example 2; displays all the blocks and connections used in a car construction project; red nodes as input blocks, blue nodes as connector blocks and yellow nodes as output blocks; thickness represents how many times the same connection is used across the project timeline

two separate code club sessions in terms of the blocks used to build their car, as well as the complexity of their design.

A final example in Figure 5.5 showcases a third student, and their experimentation with a high number of blocks across almost every permutation possible of connections between the blocks. In addition, no distinct circuits can be picked out as dominant parts of the stanza against other ones. This may be indicative of a lack of strategy in building their designs up, instead iterating through new permutations every time.

The main goal of the 'Blocks and Connections' visualisation is to show the blocks students use to implement their behaviours, and the ways in which these blocks are connected into functional circuits. This goal allows teachers to peer into the students' ideas of what blocks they consider appropriate to use and construct their target behaviours with. Furthermore, the thickness of the connections also allows teachers to observe which circuits students worked on more or less, and where they focused their iterative efforts. Some of the reflection questions that the visualisation might help teachers investigate include the reasons for choosing specific blocks and connections, as well as the strategies the students employ in filtering out blocks and connections to build their designs. For example, do specific circuits emerge as predominant across the stanza, or are the student's efforts distributed

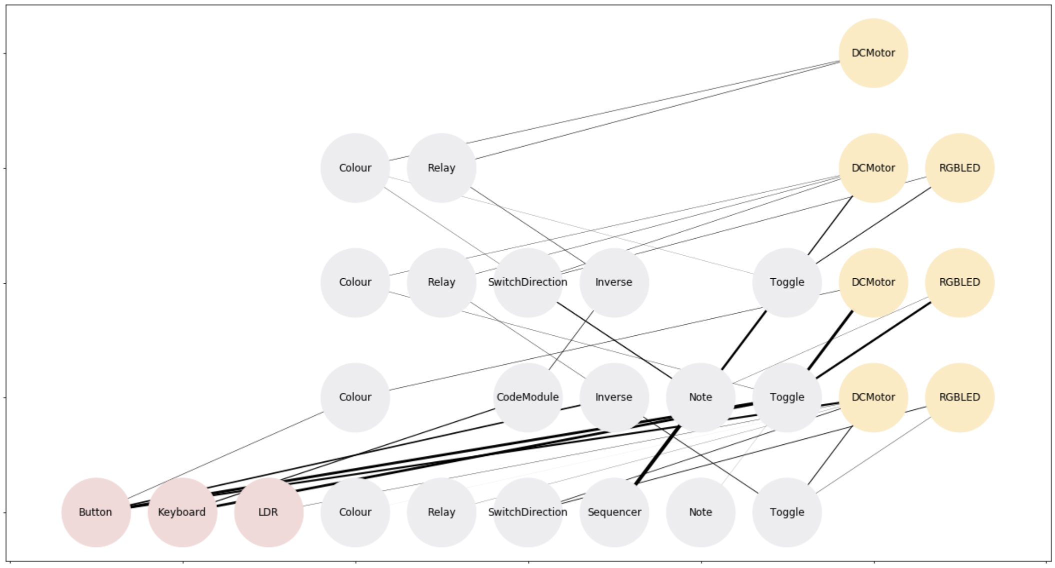


FIGURE 5.5: Blocks and Connections example 3; displays all the blocks and connections used in a car construction project; red nodes as input blocks, blue nodes as connector blocks and yellow nodes as output blocks; thickness represents how many times the same connection is used across the project timeline

equally across the various blocks and connections they create?

Block across contexts

The 'Blocks across context' visualisation aims to show all the circuits a specific SAM Labs block is used in across a stanza. The first example in Figure 5.6 displays all the different circuits which include the use of a Keyboard block across a stanza. The visualisation is a 2D graph, where the nodes represent the SAM Labs blocks and the edges are the connections between the blocks. The visualisation displays all the circuits in which a specific block is used, indicative of the functionality contexts in which a student tries to use a particular block in. Similarly to the 'Blocks and Connections' visualisation, the red nodes indicate input blocks, blue nodes indicate connector blocks and yellow nodes indicate output blocks. The width of the lines is representative of the number of lines the connection appears in across the stanza.

In Figure 5.6, the Keyboard is used as an input to trigger a DC Motor, a Player and an RGBLED directly, as well as two circuits activating a DC Motor and a Player through a Switch Direction. The color coding is representative of the type of block: red representing an input, blue a connector and yellow an output, with the block being queried replaced as bright red. The visualisation allows a focus onto the uses of a specific block in the context of a stanza.

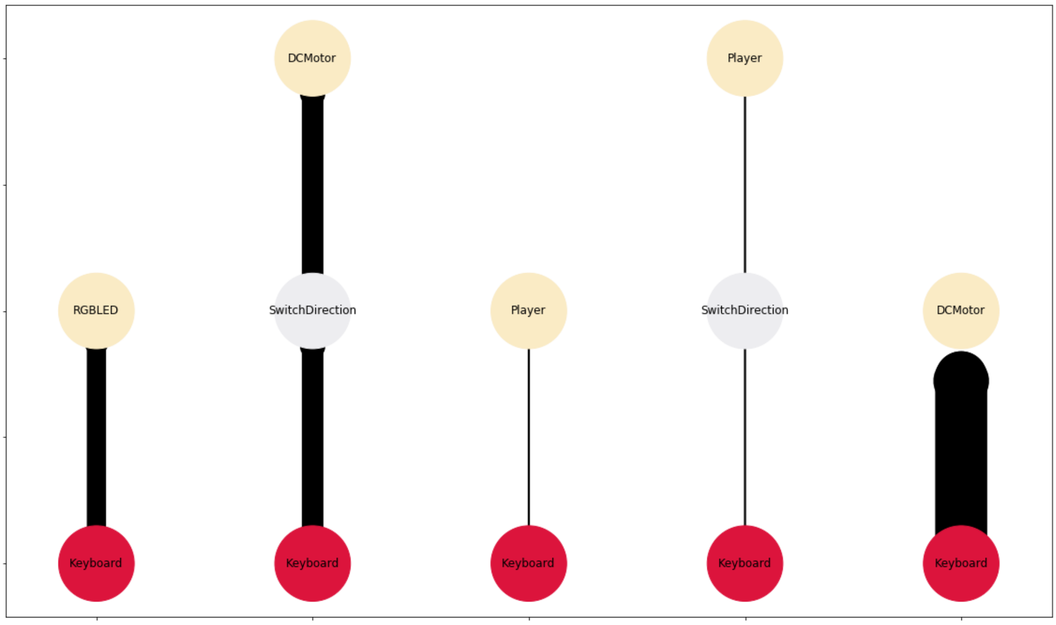


FIGURE 5.6: Blocks across Contexts example 1; displays all the circuits which use the Keyboard block from a car construction project; red nodes as input blocks, blue nodes as connector blocks and yellow nodes as output blocks; thickness represents how many times the same connection is used across the project timeline

In Figure 5.6, three circuits use the Keyboard to trigger the RBG LED, Player and DCMotor by connecting the blocks directly. In the context of building a car, the three uses of the Keyboard could signify using the Keyboard to power the wheels, turn on headlights and maybe a beeping horn as the Player. Whilst the three circuits are very similar in terms of SAM Labs design, they play very different roles in the students' car construction. The student also tries the SwitchDirection connector across two contexts: (i) in the context of powering the DCMotors, which would correctly change the direction in which the motors spin, therefore making the car drive the opposite way; (ii) in the context of powering the Player, which would simply render the circuit invalid and prevent the Player from working altogether, as the Player is incapable of understanding the Switch Direction instruction.

The second example in Figure 5.7 highlights the use of a Toggle block. The Toggle is used in association with the Keyboard input and the Switch Direction connector, and even a Note and Color block, although those are the most infrequent uses. The use indicates the student is trying to implement both a Start / Stop and Left / Right car movement in the same circuit, using

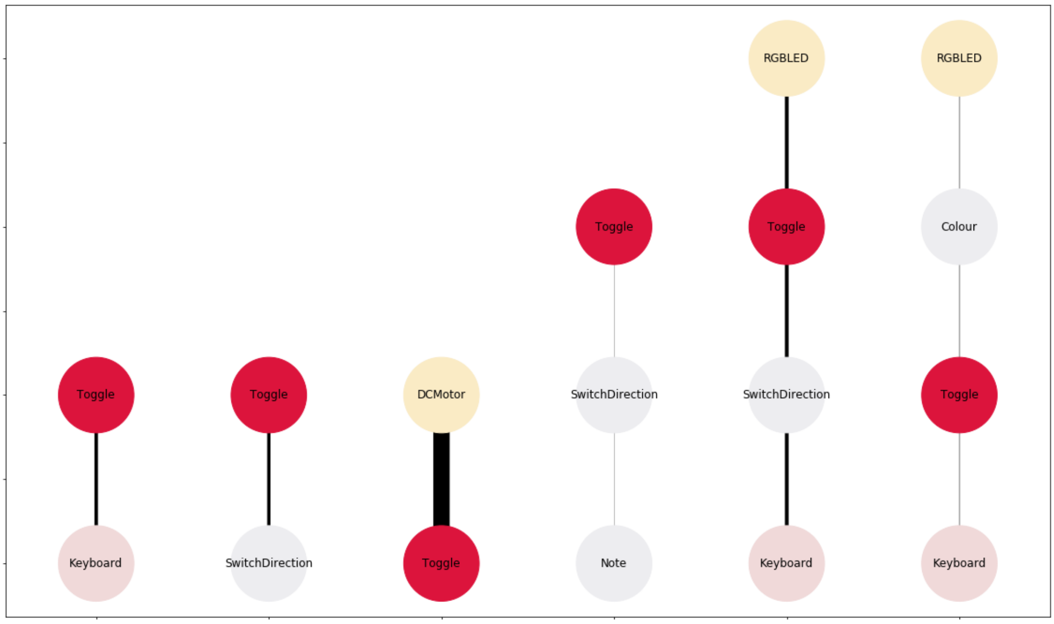


FIGURE 5.7: Blocks across Contexts example 2; displays all the circuits which use the Toggle block from a car construction project; red nodes as input blocks, blue nodes as connector blocks and yellow nodes as output blocks; thickness represents how many times the same connection is used across the project timeline

the blocks together. Whilst this might be a valid circuit to build – stopping or starting followed by changing the direction in which the motors spin, it wouldn't achieve the project brief, which requires the students to change the direction of the motors in motion without the car stopping first.

Finally, the use of the Color block is looked into in Figure 5.8, as a more unusual block of choice in the construction of a car. We can see the different ways in which the student attempts to use the Color block, none of which are valid, being used in connection with a DC Motor which cannot interpret a Color instruction.

The main goal of the 'Blocks across Contexts' visualisation is to show all the distinct circuits in which a specific block is used, to allow teachers to query the students' iterations for specific blocks. This goal allows teachers to investigate the functionality goals students use specific blocks for, and the circuits which they use to implement those goals, to query further the different hypotheses students make around the ways in which blocks function. Inquiring into the specific contexts in which the blocks are used by reviewing the circuits students build with specific blocks can help query the specific ways in which students use blocks to implement their desired constructions. The visualisation might help teachers reflect with students on

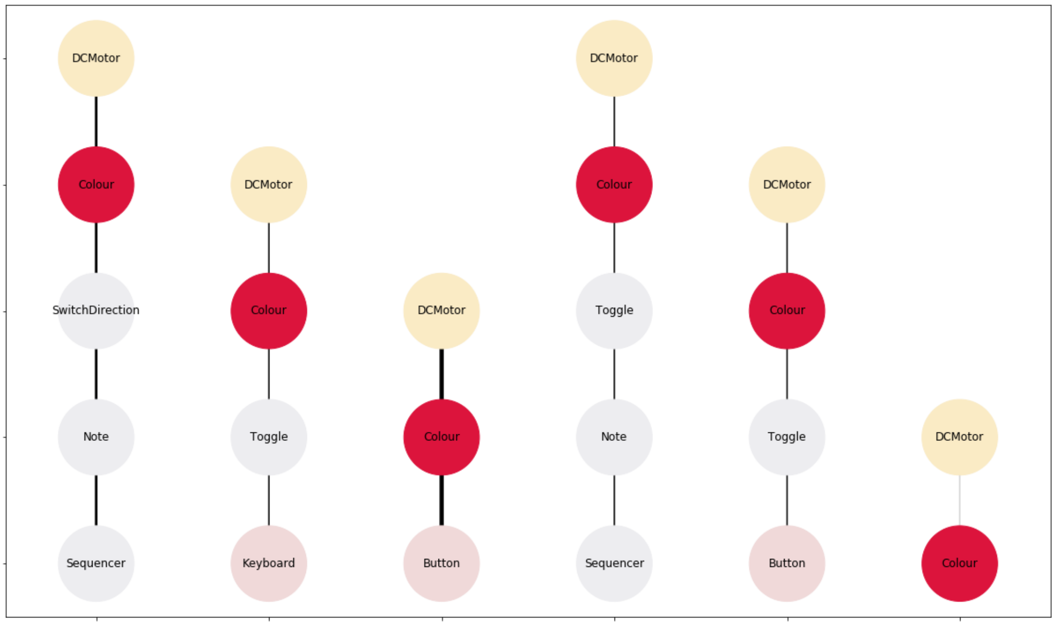


FIGURE 5.8: Blocks across Contexts example 3; displays all the circuits which use the Color block from a car construction project; red nodes as input blocks, blue nodes as connector blocks and yellow nodes as output blocks; thickness represents how many times the same connection is used across the project timeline

whether the individual blocks are used correctly in circuits, as well as query the suitability of specific blocks to achieve specific behaviours. Furthermore, teachers can analyse with students the circuits on which they spent most time iterating on based on the thickness of the connections, and investigate whether students got stuck on specific ideas.

Distinct approaches

The 'Distinct approaches' visualisation aims to show the main iterations which make up the evolution of a students' SAM Labs design. The visualisation shown in Figure 5.9 displays the different approaches student take to construct their overall design. The visualisation is a 2D graph, with the distinct approaches on the y axis and the time take to complete each approach on the x axis. The distinct approaches are separated by complete or adapted conversations. The green bars represent valid designs and the grey bars represent invalid designs. In order to select the approaches, individual lines were reviewed and versions where the design contains a complete testable graph are selected as representative of the approach. The intermediate lines where students add or remove blocks and connections in an attempt to construct a full conversation are considered intermediary, incomplete steps towards individual approaches. Furthermore, the visualisation has an interactive component. The SAM Labs design displayed in the bottom right corner in Figure 5.9 represents the final SAM Labs design the student completed their construction with. In the top left of Figure 5.9, the viewer is able to hover over each approach and view the exact SAM Labs design that approach is representative of. The interactive version of Figure 5.9 is available at `https://xhyiqp.axshare.com`.

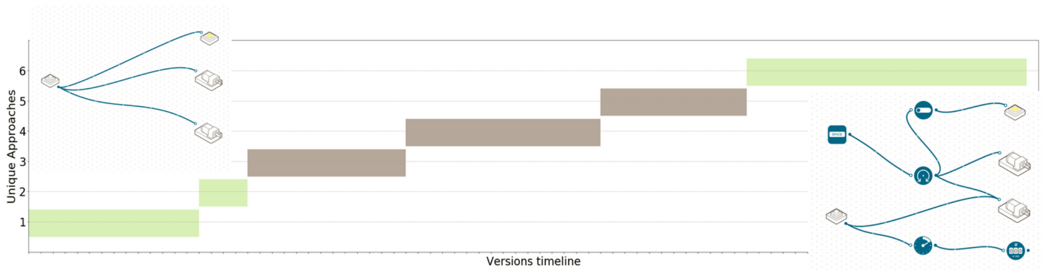


FIGURE 5.9: Distinct Approaches example 1; displays the main intermediate design approaches making up the evolution of a final car SAM Labs design; x axis number of approaches; y axis project timeline; top left corner displays intermediate designs; bottom right corner displays final design; each graph bar represents the length of time for which the student worked on a specific approach for; green bars represent valid designs, grey bars represent invalid designs

displays all the circuits which use the Color block from a car construction project; red nodes as input blocks, blue nodes as connector blocks and yellow nodes as output blocks; thickness represents how many times the same connection is used across the project timeline

The first example in Figure 5.9 showcases six distinct approaches for the construction of the car. The student starts with a straightforward design using a button to trigger both motors and a light at the same time. This would have the car moving forward with a front light continuously whilst the button is pressed. The next approach introduces a Switch Direction block for one of the motors, causing the car to alternate between going left or right every time the button is pressed and the car started. The following approaches showcase a few different attempts at integrating both the Switch Direction and the Toggle blocks in dfferent ways, some of which are SAM-valid, some are SAM-invalid. In the final design, the student uses two separate inputs – a Button and a Keyboard, to activate the motors and the light separately, and a counter for measuring the car's speed. The student takes the same car construction design through various iterations, some more complex than others. It can be observed however that the design's complexity is not linear. In the penultimate approach, the student goes through simplification step before adding more back into their circuit.

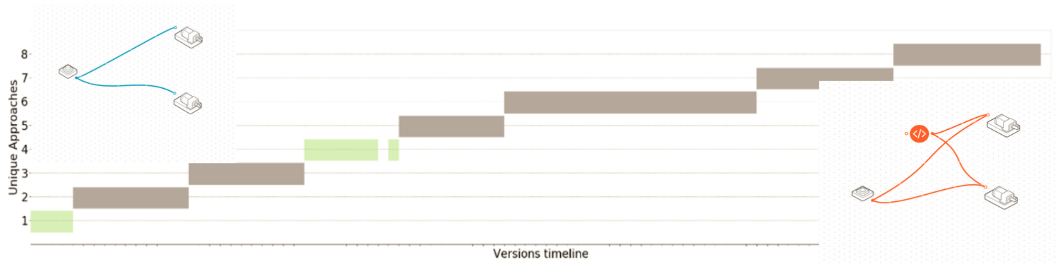


FIGURE 5.10: Distinct Approaches example 2; displays the main intermediate design approaches making up the evolution of a final car SAM Labs design; x axis number of approaches; y axis project timeline; top left corner displays intermediate designs; bottom right corner displays final design; each graph bar represents the length of time for which the student worked on a specific approach for; green bars represent valid designs, grey bars represent invalid designs

In the second example in Figure 5.10, eight approaches are identified from the students' design iterations. The interactive version of Figure 5.10 is available at `https://gqtfq0.axshare.com`. The student starts with a simple approach, increasingly adding more blocks and connections to their construction. From the penultimate approach it can be observed that the student connects almost every block to each other, and all but two of the approaches are functional. The student's final design is invalid, and a much more simplified version of most of the previously attempted designs. Displaying the changes between students' approaches in this way allows for observing not only the end design, but the intermediate steps taken to get there.

The final example in Figure 5.11 showcases a car built over five approaches. The interactive version of Figure 5.10 is available at `https://oid95a.axshare.com`. All approaches are SAM-valid, using input -> output direct connections, and with little differences between the final four designs.

The Distinct Approaches visualisation attempts to better contextualise the information by showing the students' actual designs alongside the data representation. The visualisation prompts questions over the students' progression across conversations.

The main goal of the 'Distinct Approaches' visualisation is to summarise

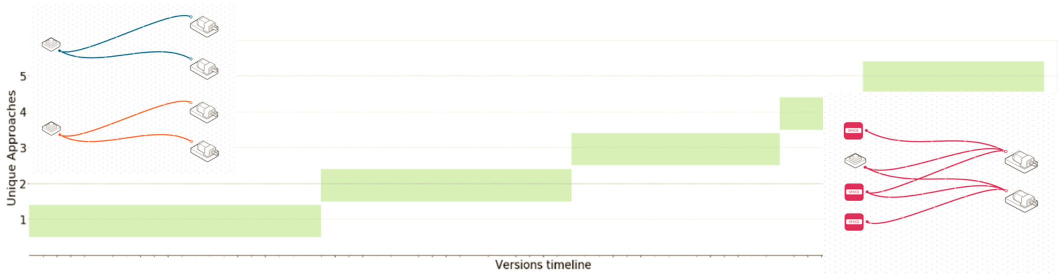


FIGURE 5.11: Distinct Approaches example 3; displays the main intermediate design approaches making up the evolution of a final car SAM Labs design; x axis number of approaches; y axis project timeline; top left corner displays intermediate designs; bottom right corner displays final design; each graph bar represents the length of time for which the student worked on a specific approach for; green bars represent valid designs, grey bars represent invalid designs

the main designs the students took their constructions through. This allows teachers to see what the main changes in students' constructions were, and compare the changes between the main versions, in this was piecing together the evolution of the students' SAM Labs designs. The visualisation doesn't only provide the bar chart of how long students spend on each approach, but also displays the design itself, as an attempt to better contextualise the information shown to teachers with what the students construct. The visualisation helps teachers enquire into the students' progression across conversations. Using the 'Distinct Approaches' visualisations, the teachers are able to reflect with students on how the approaches build on each other towards a final design, and on the reasons for students making the changes between approaches. Do the students focus on small refinements of specific areas of the construction, or do the approaches vary drastically from each other? Are the approaches aimed at find the valid way of using intended blocks, or are the approaches valid variations that don't meet students functionality goals?

Kept versus discarded

The 'Kept versus Discarded' visualisation aims to show the amount of changes discarded by the students across the project versus the amount of changes which contributed to the final design. The visualisation shown in Figure 5.12 is a 2D graph, and displays the overall number of connections tried and discarded by the students below the red line, versus the number of connections kept in the final design above the red line. Each square on the graph represents a connection between two blocks. The dark orange signifies the first instantiation of a connection in the graph, with the lighter orange a repetition of the same connection from previous versions. The same applies for the difference between dark and light blue squares above the line. The connections are displayed across time on the x axis, the y axis making up the total number of connections making up the graph at any given point in time across the duration of the project. The 'Kept versus Discarded' visualisation is a representation of the volume of changes the students make that result in a part of the graph that is kept in the final design, versus the amount of changes that get discarded as temporary experiments, ultimately removed from the final design instantiation, across a stanza. The intention is to provide a sense of quantity, rather than an inquiry into the specific connections which are either kept or discarded.

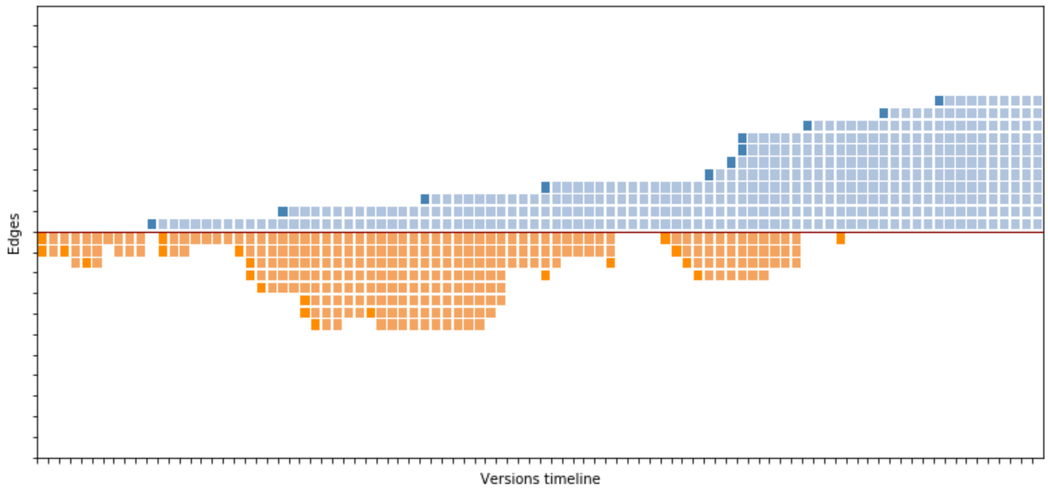


FIGURE 5.12: Kept versus Discarded example 1; displays the number of connections discarded versus the number of connections kept in the final SAM Labs design; x axis number of connections between blocks used in the design; y axis project timeline; orange squares represent discarded connections; blue squares represent connections kept in the final design

In the first example in Figure 5.12, the connections used for in student's car final design are added in a gradual manner, with the first one added a few lines into the construction, and regularly built up over time. There is also roughly an equal amount of connections which get discarded in the first two thirds of the construction time.

A second instantiation of the same visualisation in Figure 5.13 unpacks the individual connections and displays them on a separate x axis, noted on the left hand side, and coloured either in green or black depending on whether they belong to a valid or invalid circuit. This visualisation contextualises further the specific connections that get discarded, as well as the validity of both kept and discarded work.

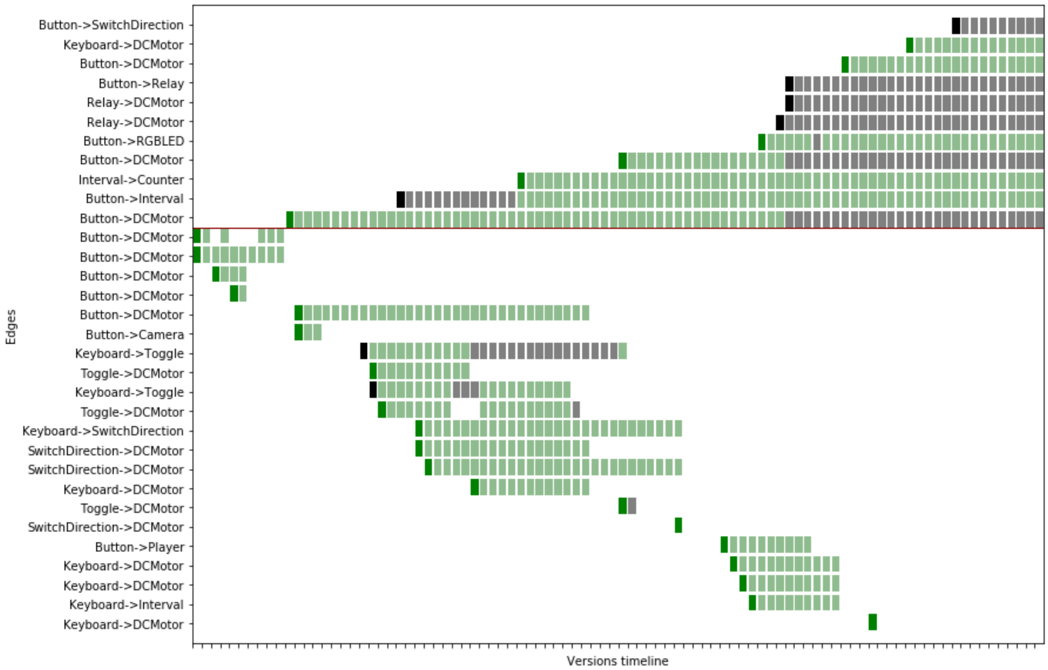


FIGURE 5.13: Kept versus Discarded example 2; displays the number of connections discarded versus the number of connections kept in the final SAM Labs design; x axis number of connections between blocks used in the design; y axis project timeline; orange squares represent discarded connections; blue squares represent connections kept in the final design

The student's discarded connections visible in Figure 5.13 mostly belong to valid circuits, whereas half of the connections belong to the final design form invalid circuits.

In another example from a second student in Figure 5.14, the overall quantity of connections, both kept and discarded is significantly higher, with the squares represented a lot more densely in the graph. The student discards the entirety of their early work, only at the tail end of the project starting to consolidate their final design, and reducing the amount they discard.

The equivalent visualisation of the same student's Kept and Discarded changes with validity information from Figure 5.15, it can be observed that the discarded connections form part of both valid and invalid circuits. This indicates that the work being discarded is not just from circuits which don't function, but potentially those circuits that function according to the SAM functionality rules, but do not function according to the student's intentions.

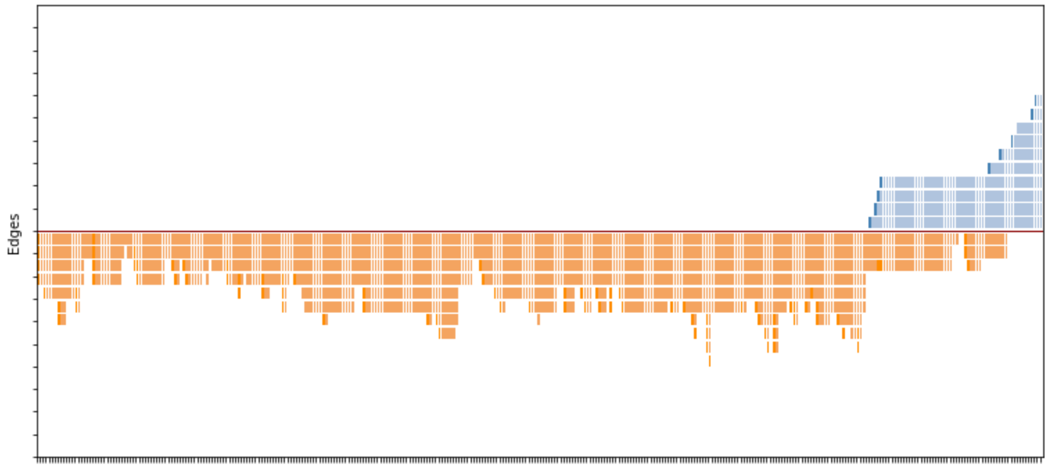


FIGURE 5.14: Kept versus Discarded example 3; displays the number of connections discarded versus the number of connections kept in the final SAM Labs design; x axis number of connections between blocks; y axis project timeline; orange squares represent discarded connections; blue squares represent connections kept in the final design

The third example in Figure 5.16 shows a student who discards very little of their design, and starts adding to their final construction right from the start.

Seen with the validity information added in Figure 5.17, the student ends up with an invalid construction, and with little validity across their whole stanza.

The main goal of the Kept versus Discarded' visualisation is to visually quantify the amount of work students discard throughout the project against the amount of work they keep and directly contributes to the end result. This allows teachers to observe the amount of discarded work students engage in but not include in their final design, therefore giving a more complete indication of the effort students put into their constructions. The teachers can use the visualisation to consider the proportion of the students' iterations which don't contribute directly to the final design, and help shift the focus on the process rather than the end result. The visualisation helps highlight the amount of discarded work necessary to build an artefact, and helps teachers reflect with students the equal importance of work that contributes to the designs but doesn't end up in the final construction.

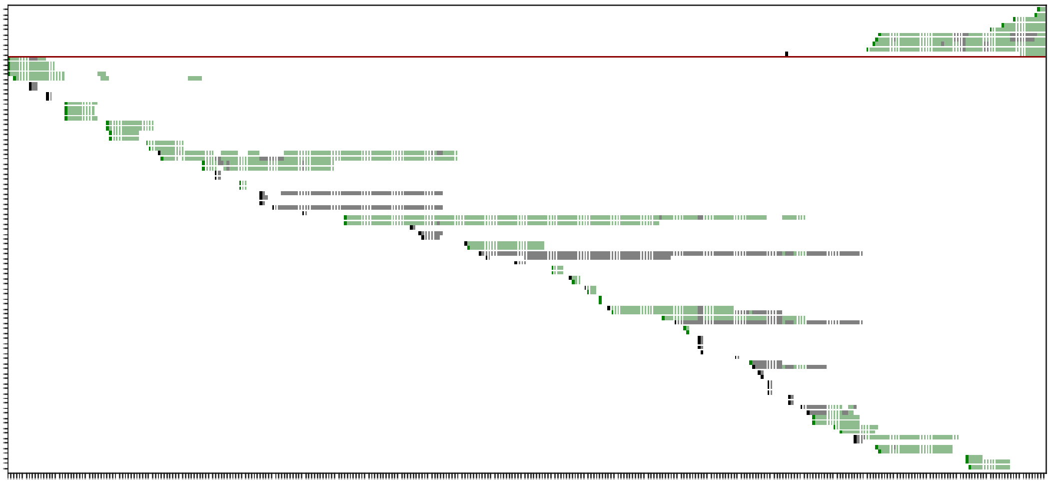


FIGURE 5.15: Kept versus Discarded example 4; displays the number of connections discarded versus the number of connections kept in the final SAM Labs design; x axis number of connections between blocks; y axis project timeline; green squares represent valid connections; grey squares represent invalid connections; squares below the red line discarded and squares above red line kept in final design

5.1.4 Summary

The visual proxies presented above describe the blocks, connections and usage of the SAM Labs components across lines, conversations and stanzas, centred around three questions:

- What blocks do the students consider appropriate to use and construct their target behaviours with?
- What iterations make up the evolution of the SAM Labs design?
- What proportion of the students' iterations contribute directly to the final design?

The visualisations reflect aspects of students' iterative behaviours, prompting specific questions summarised in Table 5.2:

The visualisations are aligned with the design goals identified in Section 4.2 of this chapter:

- Build visualisations which convey aspects of the iterative design process independent of end-product
- Design visualisations which account for the iterative design process over the long term

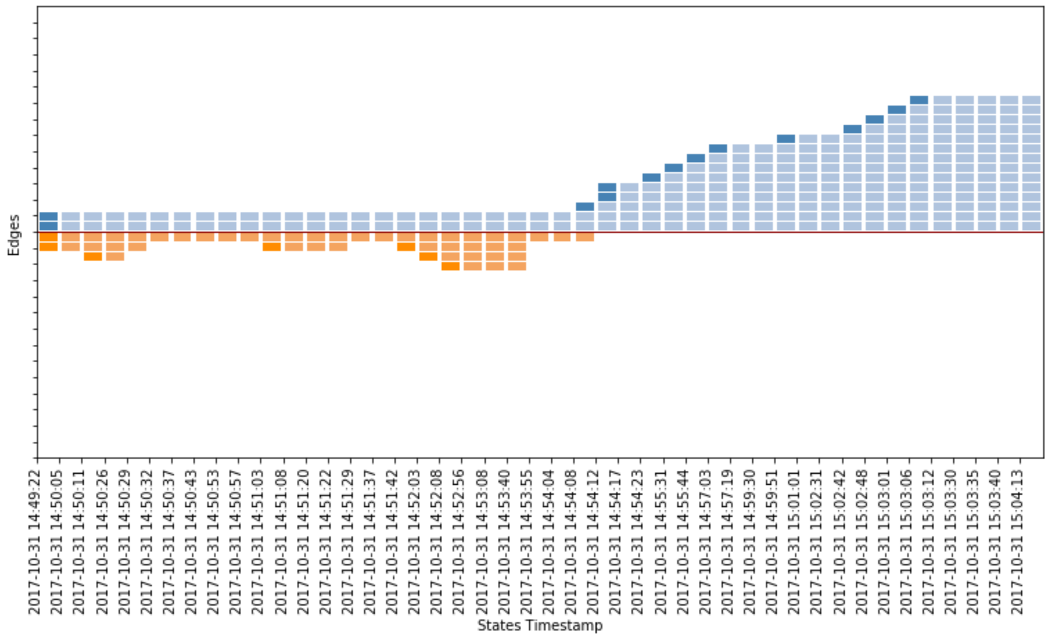


FIGURE 5.16: Kept versus Discarded example 5; displays the number of connections discarded versus the number of connections kept in the final SAM Labs design; x axis number of connections between blocks; y axis project timeline; green squares represent valid connections; grey squares represent invalid connections; squares below the red line discarded and squares above red line kept in final design

- Position the visualisations as a reflection tool

In the next chapter, we interpret the visualisations from the Keble board game project as presented above, triangulating with the video and audio data streams from each student. We explore the relationship between the visible representation of the iterative design process captured in the trace log data and the students' intentions captured through video and audio, as expressed through the appropriation model.

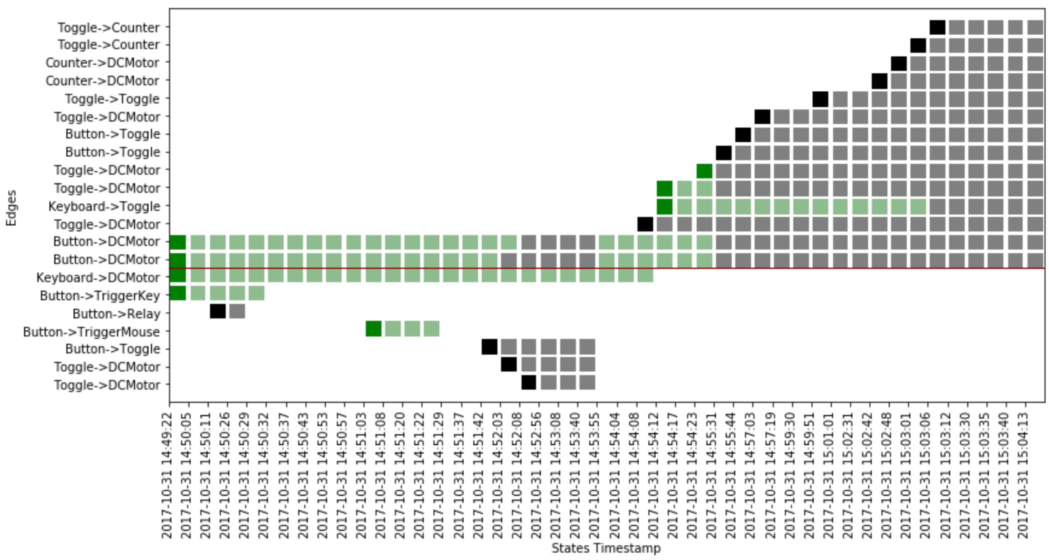
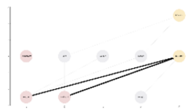
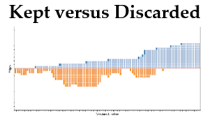


FIGURE 5.17: Kept versus Discarded example 6; displays the number of connections discarded versus the number of connections kept in the final SAM Labs design; x axis number of connections between blocks; y axis project timeline; green squares represent valid connections; grey squares represent invalid connections; squares below the red line discarded and squares above red line kept in final design

TABLE 5.2: Data Visualisations Questions

Blocks and Connections	**Blocks across Contexts**	**Distinct Approaches**	**Kept versus Discarded**
			
What is the quantity and nature of the blocks students iterate with to implement their target behaviours? What circuits are predominant in the students' iterations? How distributed are the students' iterations across the components used through the conversation?	In how many distinct ways do students iterate using the same blocks across contexts? How distributed are the students' iterations across distinct circuits in a conversation?	How many approaches do students iterate through to reach a final design? How long do students spend on each approach before adapting it? In what ways do the iterations inform each other as they evolve through the stanza?	What is the volume of iterations across a stanza? How do the iterations split between those that contribute directly to a final design, and those that are discarded? How do the iterations used in the final design spread across the stanza?

Chapter 6

Data Analysis

In this chapter, students' iterative behaviours are explored through the data visualisations presented in Chapter 5, across three sections.

First, seven students' iterative design journeys from the Keble Prep School board game are presented. The qualitative narrative is supported by the data visualisations produced for each students' projects. The information in the visualisations is triangulated with the video, audio and digital journaling data. The seven students were selected based on the completion of the data recordings and their diversity amongst the whole cohort. The iterations each student goes through to achieve their board game constructions are explained. The Appropriation Model presented in Chapter 5 is used to explore the ways in which the students' goals and SAM Labs designs evolve in connection to each other.

Second, three dimensions characterizing the students' iterative design process are presented as they emerge from the data visualisations.

Third, iterative design patterns emerging from the data visualisations from all students are presented and discussed in the context of iterative design pedagogical concepts.

6.1 Iterative Design Student Journeys

The following section presents the journey of seven students of constructing their intelligent board games, part of their computing project at the Keble Preparatory School as presented in the second learning context of Chapter 3. The seven students were selected based on the completion of the data recordings and their diversity amongst the whole cohort. The students built, on average, two SAM Labs behaviours, with some students building as many as four, to enhance their board game in an "intelligent" fashion. The complete analysis for all students, including all the SAM Labs behaviours, is presented in Appendix K. One construction from each student is explored using the data visualisations generated for the SAM Labs designs, complemented by what the students recorded in their digital journals and the conversations captured in the audio and video recordings. A summary of the students and the main observations from their constructions is presented in Table 6.1. The students' audio transcripts are included in Appendix G.

The analysis of the data follows the Appropriation Model to investigate the following:

- The students' iterative activity
- The evolution of students' goals in line with what they implement in SAM Labs

There are three main board game intelligent behaviours the students worked on, as guided by the teacher and shared between students in the classroom:

1. Automatic dice

   All students implemented a type of dice using SAM Labs, implementing different ways of letting players know how many spaces they should move forward on the board. Some students decided to use Players and record voice instructions on how many spaces the players can move, some signalled the same information through lights, and some used a Motor to power a 3D printed wheel built on a numbered circle to simulate a spinner landing on a number from 1 to 6. An example of a physical spinner triggered by a Button is exemplified in Figure 6.1.

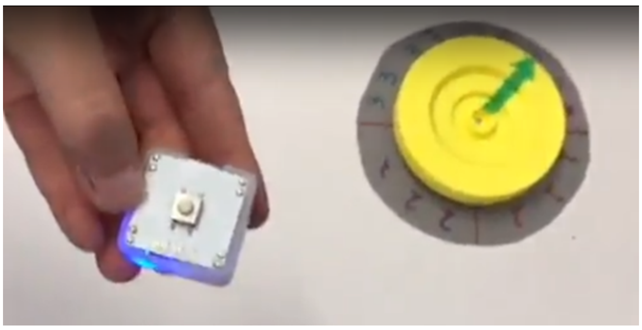


FIGURE 6.1: Physical Dice Construction Example

2. Motorised trapdoors

TABLE 6.1: Summary of the twelve students' constructions and attitudes

S	Item	Data	Iterative Design Approach
K	Dice	Complete	Low amount of iterations and low confidence in their ideas at the start of the project, but increasingly more iterative and confident throughout
N	Trapdoor	Complete	Confident in their ideas from the start and willing to try unknown functionality, but mostly remaining within their comfort zone
A	Trapdoor	Complete	Generating multiple ideas and confident from the start, engaged in high levels of iterative design activity throughout the project
R	Dice and Light Effect	Complete	Inventive and keen to engage in the project but keeping their level of construction and iteration low and simple
J	Trapdoor	Complete	Unsure about their own ideas, implements similar functionality as other students, but engages in depth with each idea and iterates heavily on small details
E	Sound Effect	Complete	Unsure about the project and low in confidence to test their ideas without supervision
F	Trapdoor	Complete	Curious to try out their own ideas but reluctant to break already working designs or make it too complex
G	Dice	Incomplete	Tentatively trying out their own ideas but seeks constant reassurance from teachers
X	Light and Sound effect	Incomplete	Keen to push their own knowledge of SAM Labs and tries to find ways of incorporating new functionality (Similar to Student A)
B	Trapdoor	Incomplete	Generates lots of ideas (mostly unfeasible) but unsure about how to implement most of them and keeps their design very simple (Similar to student R)
Q	Light Effect	Incomplete	Finding few ideas they could implement and unwilling to test beyond their comfort zone
P	Sound Effect	Incomplete	Reluctant to generate many ideas at first, and mostly testing the components to arrive at potential feasible constructions, increasingly engaged towards the end (Similar to student K)

Another interactive element most students incorporated into their board game was a trapdoor. The trapdoor was in keeping with the Tudor theme the students applied to their board games, and the students implemented it in different ways. Some focused on the timings and movement of the trapdoor on the pizza board, making the fall of the player pieces as accurate as possible, whilst others focused on sound effects such as warning or falling sounds to accompany the motorized trapdoor. An example of a physical trapdoor, activated by a Servo-Motor with a 3D printed axe attached, and activated b a Motor is presented in Figure 6.2.

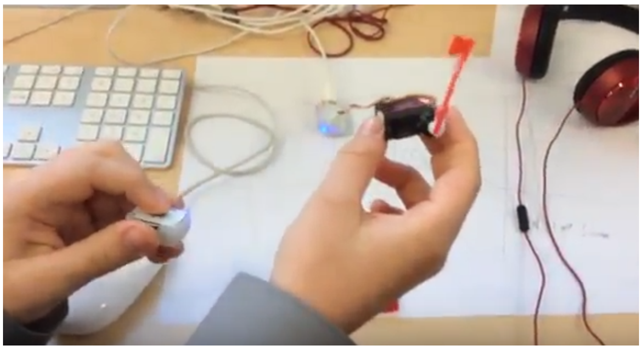


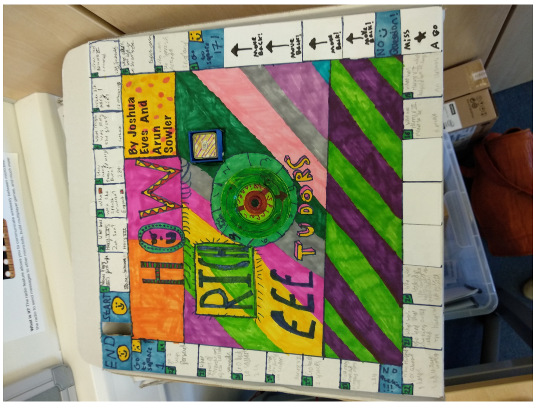
FIGURE 6.2: Physical Trapdoor Construction Example

3. Effects for players as they move on the board

   Finally, most students incorporated some form of sound or light effects to be triggered as the players reach different parts of the board. Examples include "Welcome" noises triggered as the board is open to welcome the players, lights which signify players have to answer history quiz questions in order to progress or sounds that are triggered randomly during the game sending players back to the start, as a means of making the game more exciting. Four board games in their final state are presented in Figure 6.3. The board games include the spinners for dice, lights for quiz questions, pressure pads for sound effects and trapdoors opening certain spaces on the board.

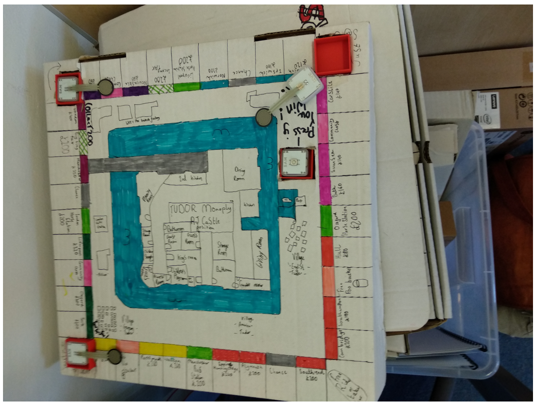
6.1.1 Student K

Student K struggles to identify a board game he wants to implement in the first lesson. He considers a few different ideas, a five-second rule game, or a question-and-answer card game, but is hesitant about starting to work on prototypes. He is also reluctant to upload his sketches to SeeSaw: "I don't



(A) Board Game 1

(B) Board Game 2



(C) Board Game 3

(D) Board Game 4

FIGURE 6.3: A subset of 4 board game final designs. Top left game implements an automatic dice and a welcome sound effect; top right game implements an automatic spinner, 2 trapdoors and 2 pressure sensors for quiz questions; bottom right game implements lights and sounds effects and an automatic spinner; bottom left game implements pressure sensors for quiz questions

think the initial drawings are very good. Can I just write a note about what I'm thinking?". When the teaching assistant asks about his progress, Student K tries to ignore him: "What are you up to atm?" <no answer> "So what are you actually doing?" Student K mostly mumbles and avoids an answer. The teacher notices his initial lack of engagement, and comments at the end of the class: "One thing I wasn't happy with was his attitude. He seemed to lack focus and enthusiasm."

By the third lesson, Student K changes the game plan altogether, deciding to implement a snakes and ladders board game instead. However, he adapts the snakes and ladder game to include questions the players would have to answer when landing on specific places on the board, with a five-second time limit. This is the first iteration Student K makes to his overall game plan.

By the end of the project, Student K builds a question buzzer, a dice, a light effect and a trapdoor for his board game. The question buzzer is a simple design, but it triggers a change in attitude for Student K. He decides "I'm going to stick to SAM", and starts working on a dice.

Dice

The dice construction involves five different approaches, as seen in the Distinct Approaches visualisation in Figure 6.4. The interactive version is available at `https://6he1j7.axshare.com`.

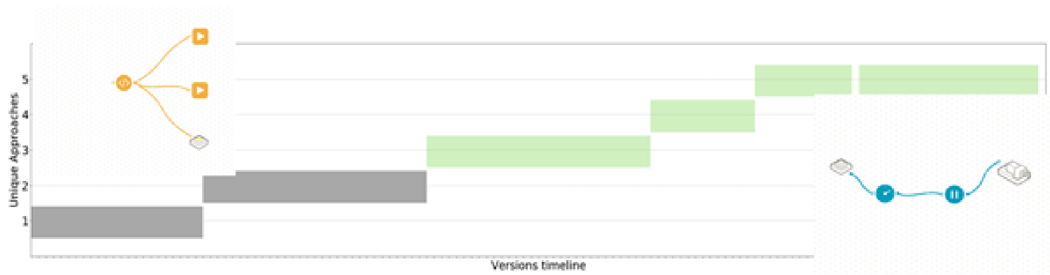


FIGURE 6.4: Student K's Dice Distinct Approaches. Visualisation shows 5 distinct approaches the student iterated through to reach their final design. Number of approaches across the y axis; the project timeline across the x axis. The green bars signify a valid design and the grey bar signifies an invalid design. The top left image displays the intermediate designs as the bars are hovered over, and the bottom right displays the final design for comparison

The way in which the students' goal gets increasingly accurate and the specific SAM Labs changes that accompany the evolution of his dice design through the five approaches is summarised in Figure 6.5. The diagram of five circles correlates to the five distinct approaches shown in Figure 6.4. The left label in each circle names the students' overarching behaviour goal, and the right label names the specific design iteration which implements the goal. The diagram was produced manually, separately to the data visualisations built in Python using trace data, as a result of the video and audio analysis which was used to identify what the student was trying to build, labelled on the left, and map it to the functionality the student implemented visible from the trace data, labelled on the right. The diagram highlights the continuous optimisation between students' theoretical goals and their practical implementation, identified earlier in the thesis as the basis for appropriation. The same diagram accompanies all 'Distinct Approaches' visualisations for all 7 student journeys presented in this chapter.

As summarised in Figure 6.5, student K aims to build a randomised dice, inspired by his classmates. In the first two approaches, he starts by replicating some of the SAM Labs designs seen elsewhere using the CodeModule. However, Student K doesn't know how to use it, rendering the designs invalid: "Let's test this, let's test this. That is... no I don't want it like this." As a result, Student K scales back his design to a simple Button -> DC Motor. His next iterations involve improving the randomising effect of the dice. The last three approaches are valid, within Student K's comfort zone: "Oh wait, OMG this is going to be the best randomiser... I'm going to put a delay in it".

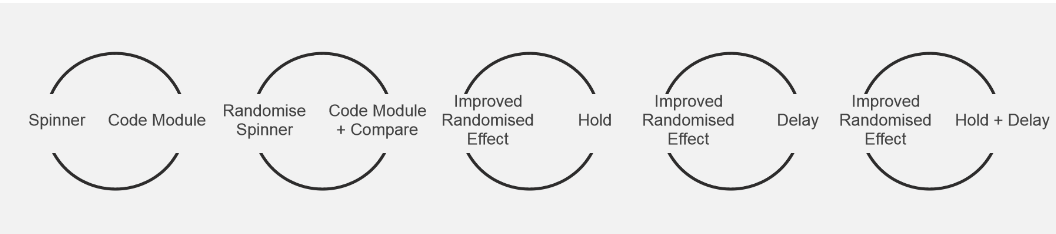


FIGURE 6.5: Student K's Dice Goal-Design Evolution. The 5 circles correlate to the 5 distinct approaches the student took to implement their dice. The left label names the behaviour goal and the right label names the corresponding functionality change to implement the goal. The evolution across 5 approaches highlights the continuous optimisation between students' theoretical goals and their practical implementation, linked to appropriation

The Blocks and Connections visualisation in Figure 6.6 displays Student K's attempts of using the CodeModule, as well as the different configurations of implementing the spinner using the Button and DCMotor. An equal distribution between iterations can be observed, with an equal amount of time spent on the different experiments, also reflected in the Distinct Approaches visualisation.

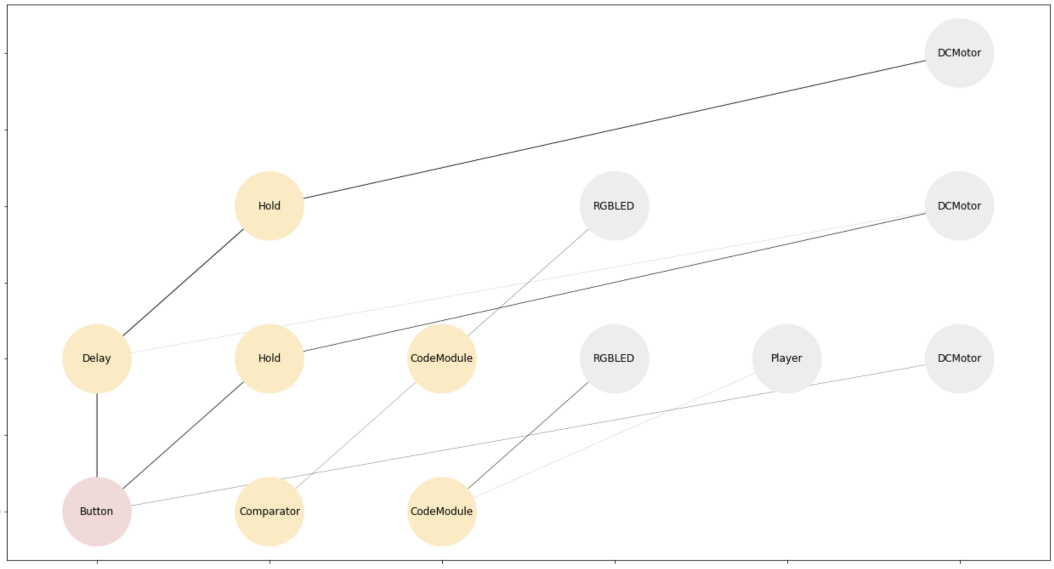


FIGURE 6.6: Student K's Dice Blocks and Connections. The student used a total of 8 blocks connected across 6 circuits to implement their dice. The graph displays the SAM Labs blocks as nodes and the circuit connections as edges between nodes. The width of the edges signifies the number of times the same connection is used across the project timeline. Input blocks are red, connector blocks are yellow and output blocks are blue.

The Kept versus Discarded visualisation in Figure 6.7 shows that most of the design work was discarded before arriving at the final version of the dice. In addition, it shows the invalid circuits Student K started to build using the Code Module, before switching approaches with increased validity.

Student K gets gradually more comfortable uploading his work to SeeSaw over the course of the project and explaining his workings, as seen in Figure 6.8.

6.1.2 Student N

Student N has a clear idea of what board game he will implement "My game is Wives and Ladders", a take on Snakes and Ladders with the required history spin on it, but is unsure about his SAM Labs construction: "I don't know how we'll make the game intelligent. I've got the die roll, once you

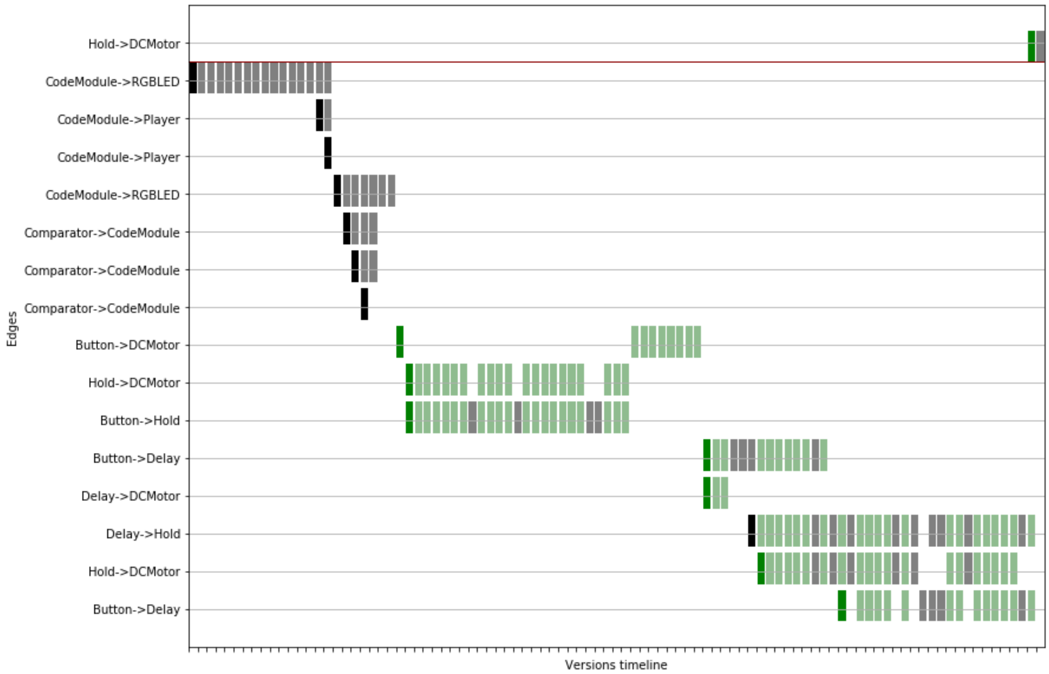


FIGURE 6.7: Student K's Dice Kept versus Discarded. The red line separates the connections between blocks discarded throughout the project below the line from the connections between blocks kept in the final design above the line. Green marks a valid connection, whilst grey marks an invalid connection.

start. But I can't think of anything else." He builds two main behaviours for his board game: an automatic dice and a trapdoor.

Trapdoor

For his trapdoor, Student N starts with a simple construction using a ServoMotor to activate it, and adds in a simple colour effect, initially separated from the trapdoor. However, he is uncertain about how the behaviours fit into his game, constantly checking whether the behaviours are suitable for the project with his teacher: "Would this work?" "It's a random noise for now, but maybe a trumpet noise when you open the box..". The teacher offers reassurance, and Student N continues to refine his construction over six main approaches, as seen in Figure 6.9. The interactive version of the Distinct Approaches visualisation is available here: https://tmi0sr.axshare.com.

Student N is comfortable with testing different versions of his behaviour, without a precise idea of what he would like the final design to be: "I'm doing a random colour generator. If you land on a block...", "The idea

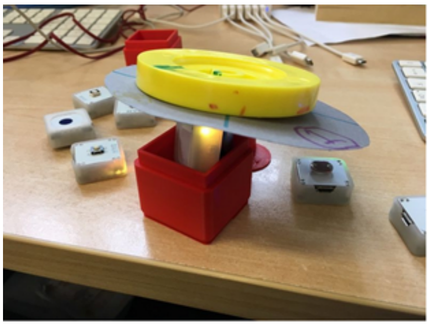


FIGURE 6.8: Student K's Dice Physical Construction uploaded to SeeSaw

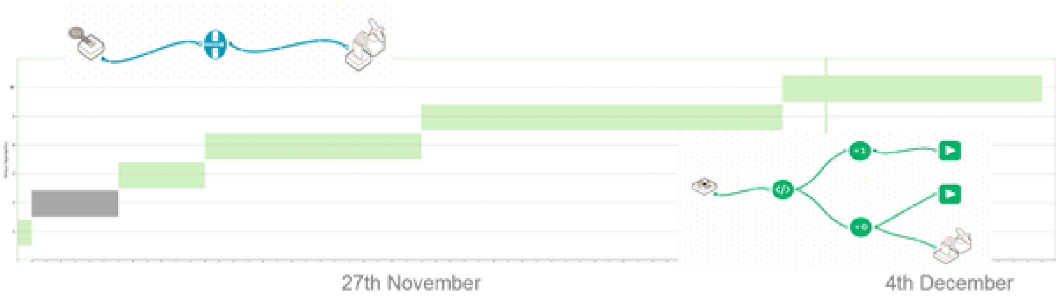


FIGURE 6.9: Student N's Trapdoor Distinct Approaches. Visualisation shows 6 distinct approaches the student iterated through to reach their final design. Number of approaches across the y axis; the project timeline across the x axis. The green bars signify a valid design and the grey bar signifies an invalid design. The top left image displays the intermediate designs as the bars are hovered over, and the bottom right displays the final design for comparison

is. . . I'm testing this". On completing a second design, he verifies his design with his friend, which gives him the idea of a sound accompanying the servomotor: Student N: "The proximity sensor works with the servo motor. What do you expect to happen exactly?" Friend: "It will say 'You are dead!'" Student N: "I can have a scream!". This results in Student N merging the sound effect behaviour with the trapdoor, resulting in a circuit which uses a Proximity Sensor to trigger the ServoMotor, using a CodeModule and Comparator connectors to manage the proximity sensitivity and the timings of the sounds against the trapdoor movement: "I've got something really good here, hang on. It's going to go through the Delay, then it goes through the SAM player, then it goes.." "I'm almost there". The way in which Student N's trapdoor design evolves from two separate behaviours into one, and the different features that get added on as the construction progresses against the changes in the SAM Labs design is summarised in Figure 6.10.

The Blocks and Connections summarises the circuits used across Student

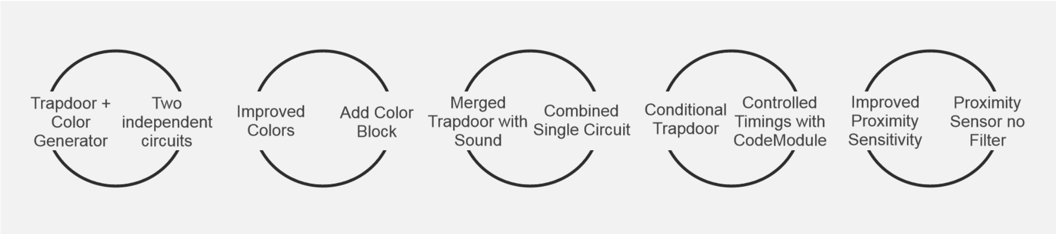


FIGURE 6.10: Student N's Trapdoor Goal-Design Evolution. The 5 circles are linked to the 6 distinct approaches the student took to implement their trapdoor. The left label names the behaviour goal and the right label names the corresponding functionality change to implement the goal. The evolution across 6 approaches highlights the continuous optimisation between students' theoretical goals and their practical implementation, linked to appropriation

N's trapdoor iterations, with an equal distribution amongst components in Figure 6.11.

The Kept versus Discarded visualisation in Figure 6.12 showcases most of the Student N's work as valid, with the iterations contributing to an adjusted construction to better suit the board game, rather than fixing a functionality issue.

Student N's physical trapdoor construction is displayed in Figure 6.13. Student N displays an open attitude to testing and adapting his trapdoor design. However, a hesitancy towards what is suitable to build in the first-place results in him implementing only two SAM Labs elements on the board game.

6.1.3 Student R

Student R makes a keen start on the game, sure of his Monopoly idea: "I know EXACTLY how this is going to look", but without fitting in any SAM Labs intelligent behaviours: "We can forget about the SAMs, and just do it like that, like the original"

Dice and Lights

Eventually, he starts working on a single intelligent element, a Dice and Light effect, taking five approaches to reach a final design, as seen in Figure 6.14. The interactive version is available at `https://dubmqm.axshare.com`.

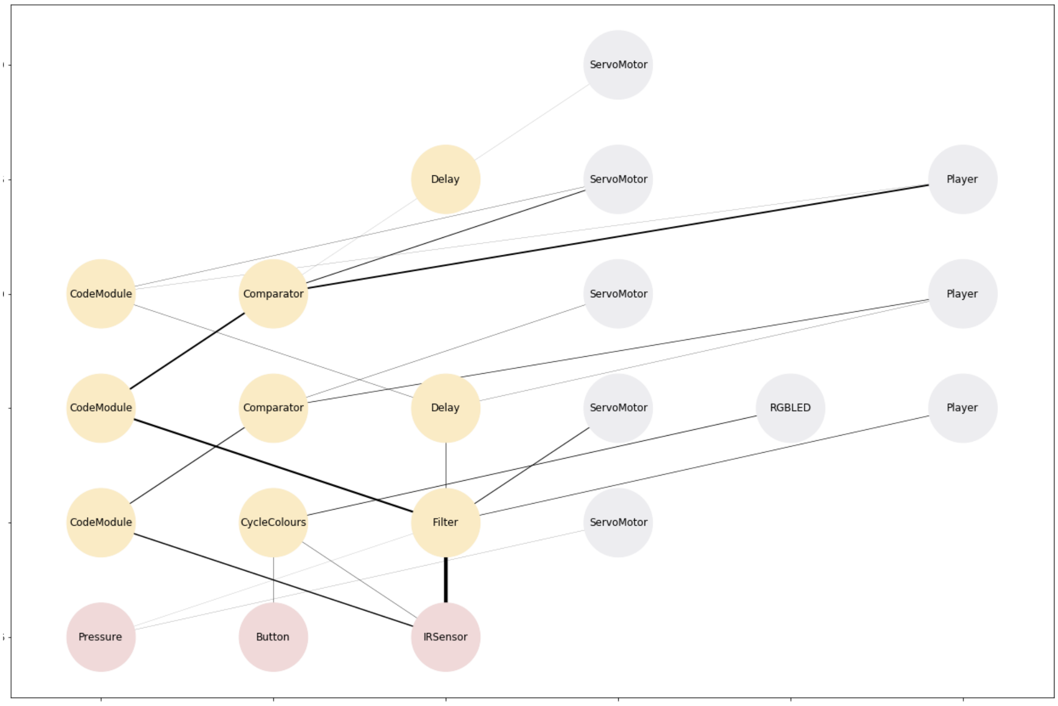


FIGURE 6.11: Student N's Trapdoor Blocks and Connections. The student used a total of 11 distinct blocks connected across 12 circuits to implement their trapdoor. The graph displays the SAM Labs blocks as nodes and the circuit connections as edges between nodes. The width of the edges signifies the number of times the same connection is used across the project timeline. Input blocks are red, connector blocks are yellow and output blocks are blue.

The exact use of the SAM Labs behaviours on his board game emerges as he iterates through from one approach to the next. "So say 4, 1,2,3,4 on each corner of the board..", "So when you land on Go you get a light, and when you land on jail it will say 'Go to jail'... can it set off a buzzer?", "That.. that.. I was thinking, maybe a buzzer. So if it was to buzz 2 times, you move twice, so you move as it buzzes." Figure 6.15 summarises the construction goals in parallel with the SAM Labs changes, kept to basic improvements.

The 'Blocks and Connections' visualisation in Figure 6.16 paints a simple view of the components tested. Student R keeping his design simple, mostly made up of direct input->output circuits, with a single connector used for changing the colors of the light in the different corners of the board game.

The Keep versus Discarded view in Figure 6.17 also shows that Student R keeps most of the circuits he implements, with little discarded along the way:

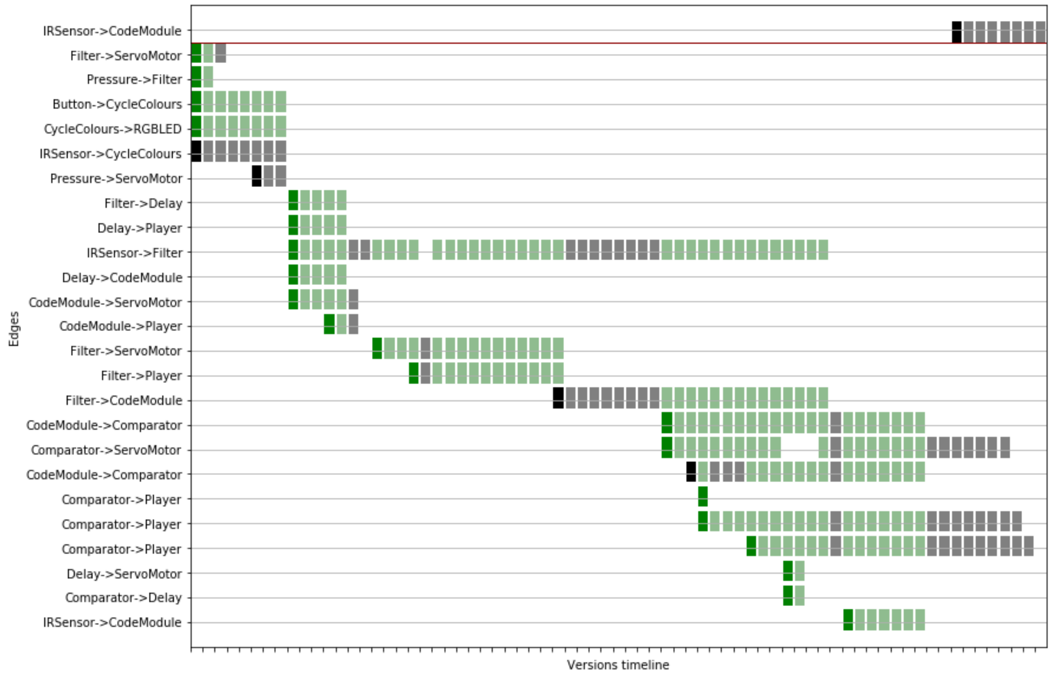


FIGURE 6.12: Student N's Trapdoor Kept versus Discarded. The red line separates the connections between blocks discarded throughout the project below the line from the connections between blocks kept in the final design above the line. Green marks a valid connection, whilst grey marks an invalid connection.

6.1.4 Student A

Student A, unlike Student K and Student N, starts the game with a few SAM Labs component ideas: "We'll have a buzzer that buzzes how many spaces you can move" and "Underneath the box I will have a beheading centre, you know one of those boxes with spikes that closes and then you die. Something like that, although that might be a bit too gruesome", which make for the first instantiations of both the Dice and the Trapdoor ideas in the classroom.

Trapdoor

For the construction of his trapdoor, Student A initially envisages having a separate box as a "beheading center", but this goal is refined in the context of the teacher's suggestion of using a ServoMotor which opens a space on the board, so Student A adapts it to have the beheading centre inside the pizza box. The Distinct Approaches visualisation in Figure 6.18 displays eighteen SAM Labs approaches iterated through to arrive at a final Trapdoor design.

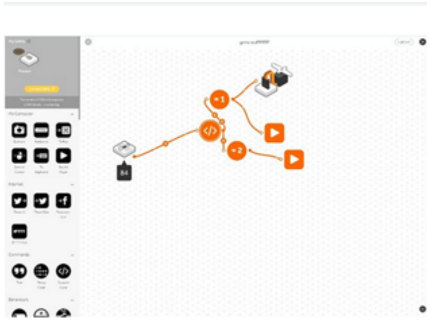


FIGURE 6.13: Student N's Trapdoor Physical Construction uploaded to SeeSaw

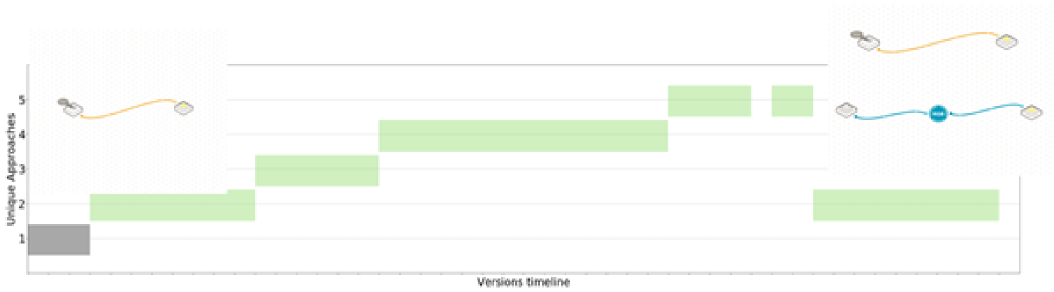


FIGURE 6.14: Student R's Dice Distinct Approaches. Visualisation shows 5 distinct approaches the student iterated through to reach their final design. Number of approaches across the y axis; the project timeline across the x axis. The green bars signify a valid design and the grey bar signifies an invalid design. The top left image displays the intermediate designs as the bars are hovered over, and the bottom right displays the final design for comparison

The interactive version is available at https://b3qxre.axshare.com/home.html.

Student A starts with two simple designs of a basic automatic ServoMotor action, but quickly implements a third more complex circuit using the Code to implement a conditional behaviour which randomly chooses between issuing the player with a warning or actually knocking them off the board. The circuit fails to work consistently, despite being valid, so Student A keeps tweaking in small increments: "So if I put it between 0 and 1.. Doesn't work :(". Student A is happy to try different options out, and is fully engaged in thinking what other solutions might work: "So what if I do..". Student A also resists implementing fixes that, despite delivering a functional design, would make for clunky usage when playing the game: "Use 2 sound players, and if it says 'Off with his head', there's just another button and you press it for the axe to come down separately, and the servo goes..No". The final Trapdoor solution is a relatively simple design, with a Pressure

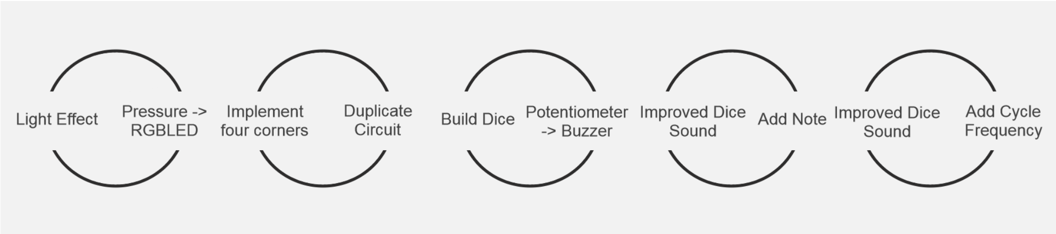


FIGURE 6.15: Student R's Dice Goal-Design Evolution. The 5 circles correlate to the 5 distinct approaches the student took to implement their dice. The left label names the behaviour goal and the right label names the corresponding functionality change to implement the goal. The evolution across 5 approaches highlights the continuous optimisation between students' theoretical goals and their practical implementation, linked to appropriation

Sensor triggering both the ServoMotor to open to box and an accompanying sound, however, is the result of a high number of iterations. Student A tweaks in small increments a design that starts with a vague goal, and gets increasingly accurate over the distinct approaches. The way in which the students' idea of the trapdoor gets adapted in light of the SAM Labs changes is summarised in Figure 6.19.

In the 'Blocks and Connections' visualisation in Figure 6.20, Student A mostly iterates through distinct connector blocks between the same inputs: Button or Pressure Sensor, and the same outputs: ServoMotor and Player. The type of connectors used: Hold, Delay, Toggle, Inverse, Comparator, indicate the precision with which Student A seeks to control the trapdoor with, looking for a specific type of movement.

Equally, the Blocks across Contexts visualisation in Figure 6.21 for the Filter block shows small refinements of the same circuit, indicative of a search for a precise solution using the same components:

Student A shows a high degree of comfort both with using the SAM Labs blocks and engaging in an iterative design process to implement his behaviours. As he iterates, he makes sure that whatever he tests is in line with his behaviours he seeks to implement: "But I need to get it random.. I tried putting each colour and when I press the button it would just do ..", and is happy to discard valid circuits which don't adhere to his goals.

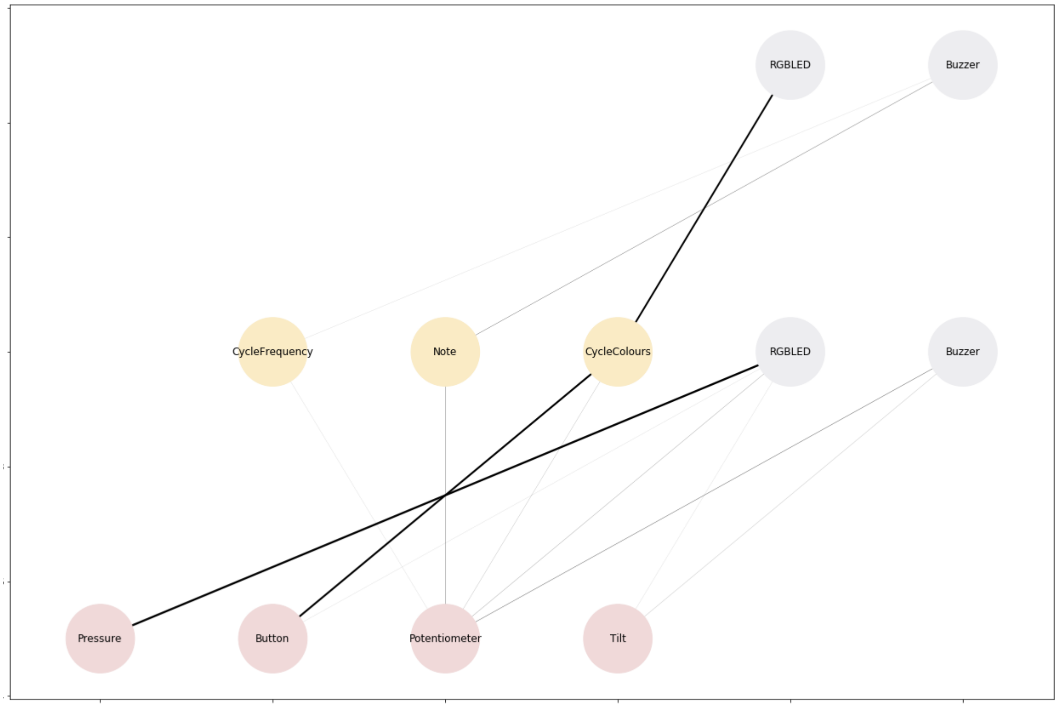


FIGURE 6.16: Student R's Dice Blocks and Connections. The student used a total of 9 blocks connected across 9 circuits to implement their dice. The graph displays the SAM Labs blocks as nodes and the circuit connections as edges between nodes. The width of the edges signifies the number of times the same connection is used across the project timeline. Input blocks are red, connector blocks are yellow and output blocks are blue.

6.1.5 Student E

Student E is unsure about what to implement in SAM Labs, and constantly double-checks his ideas with the teacher, nervous of making mistakes: "Could you have… I don't know how to put it… like a speaker, with SAM, to read out the question to you?" "Is that hard?" "So could you have something that you land on every square?" "So how would you do it?", and doesn't implement anything for the first three lessons.

Sound Effect

Eventually, Student E works on a sound effect for his board, but he continues to seek constant reassurance as he iterates through the six invalid approaches, as seen in Figure 6.22. The interactive version is available at https://sdlp8n.axshare.com. "How do I do this?" "So what do I do with this? Where do I put it?" "Oh wait, I think I've got it. Is it here?" "Will it work when I do this?"

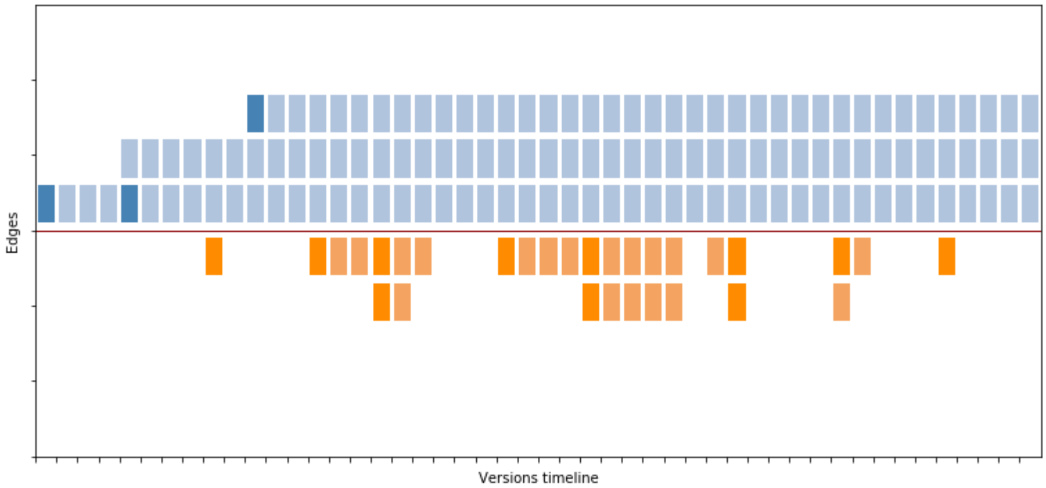


FIGURE 6.17: Student R's Dice Kept versus Discarded. The red line separates the connections between blocks discarded throughout the project below the line from the connections between blocks kept in the final design above the line. Orange marks discarded connections and blue marks kept connections.

He implements the sound effect using a Player and a Pressure Sensor to trigger it, but struggles to manipulate the amount of pressure using the Filter block. He also uses a Hold to allow the Player to output sound for five seconds, but also uses this incorrectly. The final design is almost valid, one that does generate sound even if not exactly following the Filter instruction the student tried to implement. Therefore, Student E keeps it partly working, reluctant to make any other changes that might render it completely non-functional. These changes are summarised in Figure 6.23, offering a combined view of functionality goals against design changes:

The six main iterations are based on suggestions from the teacher, however the teacher stops short of giving him the answer, instead trying to nudge him into the right direction. He resists the encouragements to test the blocks, worried about making changes, and seeking guaranteed results: "Will it work when I do this?" Teacher: "Well, you'll have to try it out." Student E: "So will I need to change this?" Teacher: "You might need to adapt and try a few different options".

The Blocks and Connections visualisation in Figure 6.24 shows an attempt to connect the Pressure Pad to the Player through the Hold and Filter connector in almost every combination, perhaps indicative of the student's limited confidence in how to build the design in the first place.

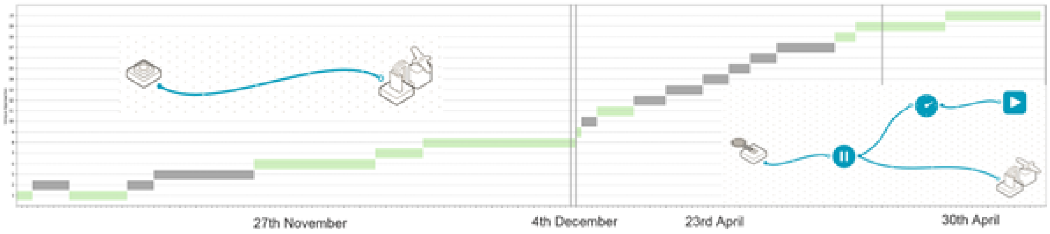


FIGURE 6.18: Student A's Trapdoor Distinct Approaches. Visualisation shows 18 distinct approaches the student iterated through to reach their final design. Number of approaches across the y axis; the project timeline across the x axis. The green bars signify a valid design and the grey bar signifies an invalid design. The top left image displays the intermediate designs as the bars are hovered over, and the bottom right displays the final design for comparison

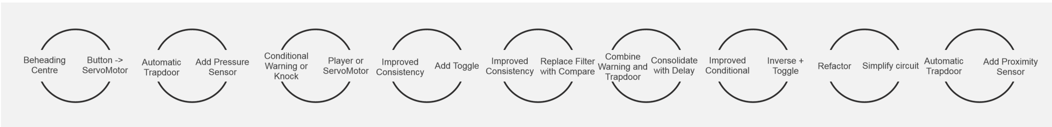


FIGURE 6.19: Student A's Trapdoor Goal-Design Evolution. The 9 circles are linked to the 18 distinct approaches the student took to implement their dice. The left label names the behaviour goal and the right label names the corresponding functionality change to implement the goal. The evolution across 18 approaches highlights the continuous optimisation between students' theoretical goals and their practical implementation, linked to appropriation

The Kept versus Discarded visualisation in Figure 6.25 with validity information shows that Student E only builds invalid circuits:

6.1.6 Student J

Student J generates several ideas at the start of the project: "I could do Trivial Pursuit. Or I can do PacMan or something like it", "I could make a game like Monopoly Tudors, but that's not original", but struggles to settle on one that he thinks is suitable: "I can't think of a good game... So, I'm trying to find other ideas. I'm gonna try to create more ideas". Eventually, he settles on inventing his own board game rather than adapting an existing one. For the SAM Labs behaviours, he talks through a few different ideas he intends to work on: "Going to use SAM for the buttons and the counters. There can be a speaker of some sorts that you can fit next to the character. If you move it there can be a SAM sensor in that place, so if you move it, it will play a sound", "I had the idea of a catapult" and having a True or False indicator for players after they answer quiz questions as they move on the

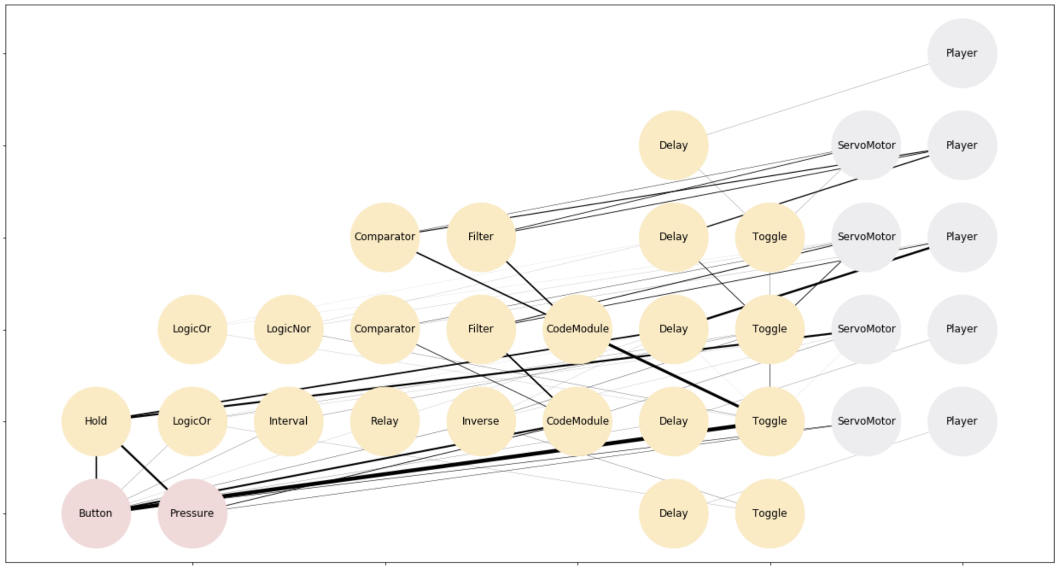


FIGURE 6.20: Student A's Trapdoor Blocks and Connections. The student used a total of 15 blocks connected across 24 circuits to implement their trapdoor. The graph displays the SAM Labs blocks as nodes and the circuit connections as edges between nodes. The width of the edges signifies the number of times the same connection is used across the project timeline. Input blocks are red, connector blocks are yellow and output blocks are blue.

board. However, none of these behaviours get implemented. Instead, Student J works on a dice and a trapdoor, the same as the other students in the classroom, which he customises for his own board game rules.

Trapdoor

For his trapdoor, Student J works through thirteen distinct approaches, as seen in Figure 6.26. The interactive version is available at https://vru9mg.axshare.com/home.html.

In the first five versions, Student J goes back and forth testing the Button and Keyboard inputs, suspecting an issue with one of the Buttons: "I was having problems with the servo last week, and I was just testing, and the button doesn't work. When I click it, it doesn't work." After trying the Slider as well and not achieving the movement he wants, he changes his approach more radically to using an Inverse to control the direction, and a light sensor to trigger the motor. For the last versions, Student J focuses on refining the way in which the trapdoor moves, the direction it opens and closes, for it to work well on the pizza board fitting. For the final design, he duplicates the design three times, for the three trapdoors he wants to have on the board.

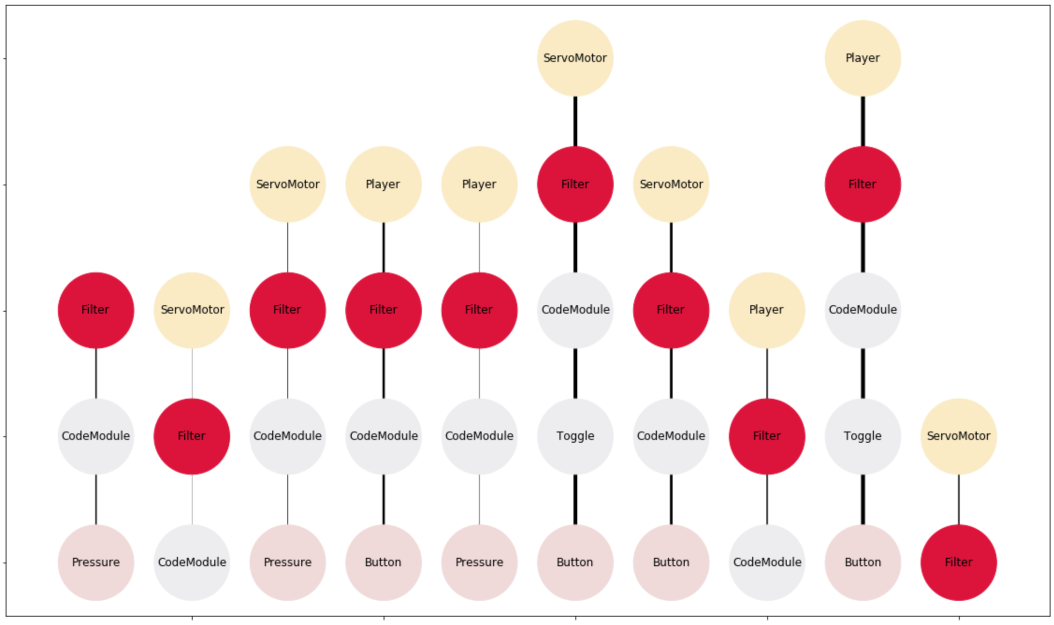


FIGURE 6.21: Student A's Trapdoor Blocks across Contexts

The Blocks and Connections visualisation in Figure 6.28 shows the predominant circuit Student J works on over the project timeline, with attempts to change the inputs and connectors to better manipulate the Motor movement. The iterations are concentrated around one main design rather than the student attempting radically different approaches.

The Kept versus Discarded in Figure 6.29 shows the final design is built up gradually from the start of the construction, with work discarded consistently across the timeline, indicative of the student's perseverance on perfecting a single design, started at the beginning of the project.

6.1.7 Student F

Student F implements his own invented board game rather than using a template based on an existing one. He generates complex SAM Labs behaviour ideas, suggesting moving the players along the board with a horse and card, or using the Pressure Pads to generate and reveal digits of a code required to win the game, however none get implemented. Instead, he keeps to three behaviours for a dice, trapdoor and light effect, using very simple circuits.

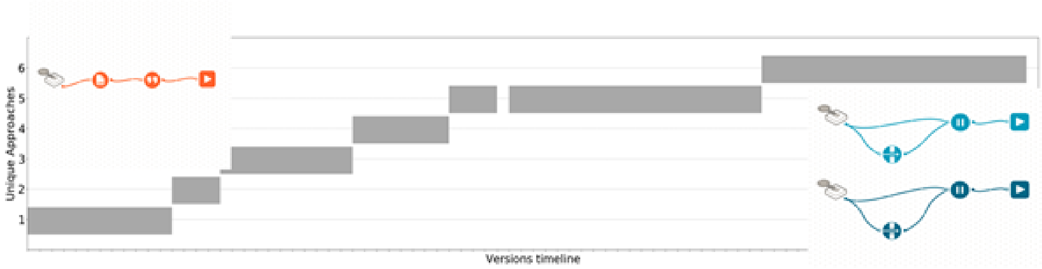


FIGURE 6.22: Student E's Sound Effect Distinct Approaches. Visualisation shows 6 distinct approaches the student iterated through to reach their final design. Number of approaches across the y axis; the project timeline across the x axis. The green bars signify a valid design and the grey bar signifies an invalid design. The top left image displays the intermediate designs as the bars are hovered over, and the bottom right displays the final design for comparison

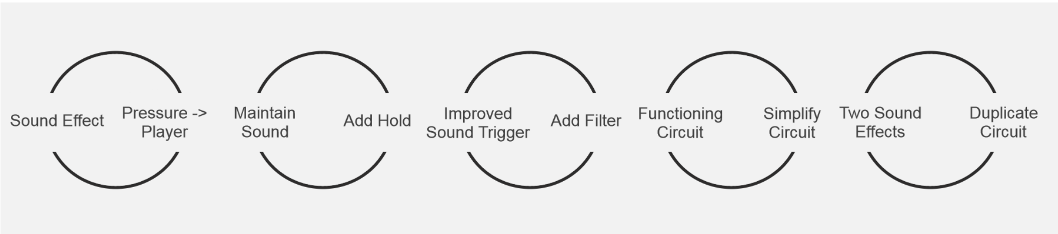


FIGURE 6.23: Student E's Sound Effect Goal-Design Evolution. The 5 circles are linked to the 6 distinct approaches the student took to implement their sound effect. The left label names the behaviour goal and the right label names the corresponding functionality change to implement the goal. The evolution across 5 approaches highlights the continuous optimisation between students' theoretical goals and their practical implementation, linked to appropriation

Dice

Student F iterates little on his dice construction, as seen in Figure 6.30, but ends very proud of his achievement: "It's done. We've done it. We've only gone and done it!!!". The interactive version of the 'Distinct Approaches' visualisation is available at `https://sou4px.axshare.com`.

The single iteration involves adding a Hold connector as an attempt to randomise the Motor's movement. However Student F realises that a Hold won't quite achieve a random effect: "No but you can still actually time it with that".

The Blocks and Connections visualisation in Figure 6.32 summarises all the circuits implemented over the course of the dice's construction.

Despite struggling to identify the SAM Labs behaviours to integrate into

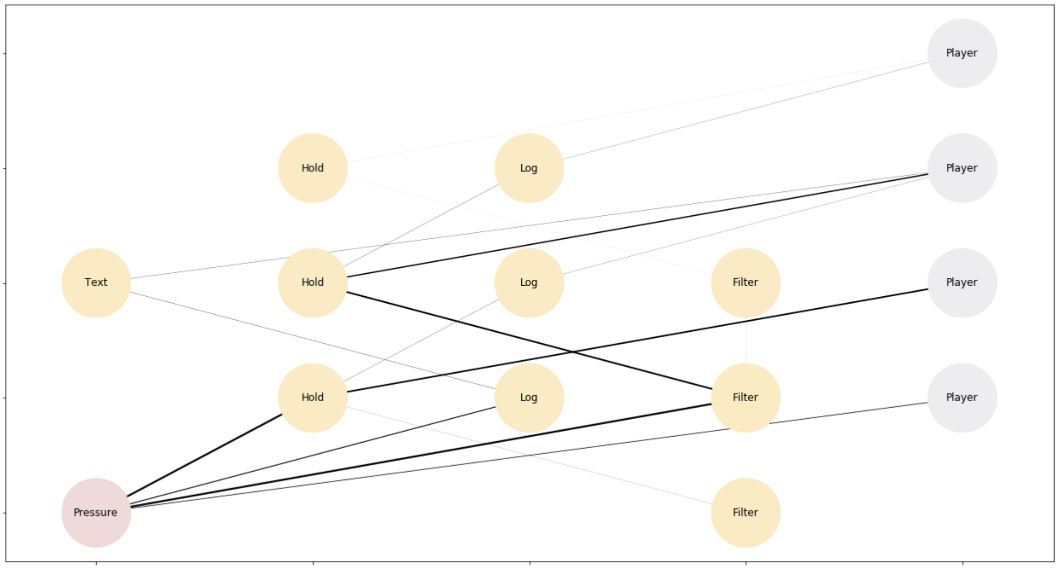


FIGURE 6.24: Student E's Sound Effect Blocks and Connections. The student used a total of 6 blocks connected across 8 circuits to implement their sound effect. The graph displays the SAM Labs blocks as nodes and the circuit connections as edges between nodes. The width of the edges signifies the number of times the same connection is used across the project timeline. Input blocks are red, connector blocks are yellow and output blocks are blue.

the board game, Student F expresses his comfort with testing different configurations once a goal is formulated: "I only introduced the servo into the project last week, so I had to play around with it, try and get it to work." Sometimes it works, and sometimes it doesn't." "Well, I don't know if it's a button or a servo, so I'm testing it out".

6.1.8 Summary

The visualisations speak to the procedural part of the students' iterations: the volume of iterations, the components making up the iterations, the changes between iterations and secondary measures such as volume kept against volume discarded, valid or invalid iterations and the frequency and time spent on each iteration. Several observations can be made with respect to the analysis of students' iterative activity from trace logs, audio and journaling data, which are further expanded on in the following two sections of this chapter:

- The video and audio, where available, complements the procedural information from the visualisations with insights into students' construction goals

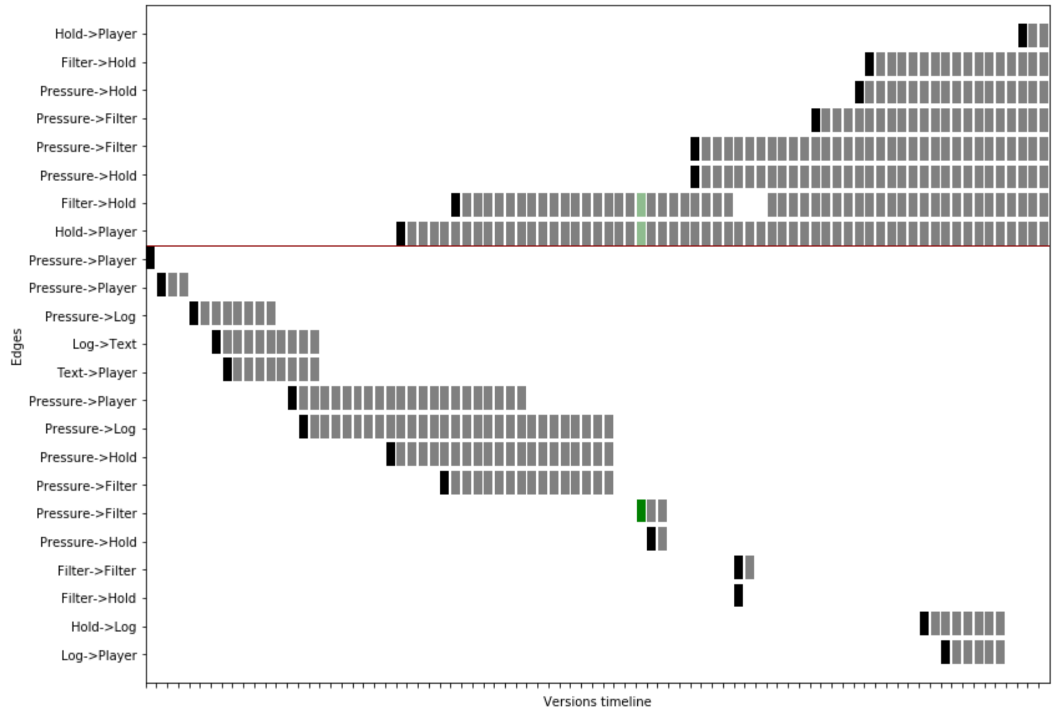


FIGURE 6.25: Student E's Sound Effect Kept versus Discarded. The red line separates the connections between blocks discarded throughout the project below the line from the connections between blocks kept in the final design above the line. Green marks a valid connection, whilst grey marks an invalid connection.

- Students' intentions for building specific behaviours act as a powerful motivator for engaging in an iterative design process
- Whilst the students build similar board game elements: dice, trapdoors and interactive effects, the construction goals and designs vary significantly from one student to another, as well as the iterative journeys taken to reach a final design
- The changes students make are intentional, with functionality goals behind them
- The final designs emerge from the intermediate iterations, rather than a fully-fledged conception at the start of the construction. Initial goals get adapted based on the feedback of the iterations and new ideas that emerge in the iterative process
- Starting with simple constructions is often a catalyst for a higher number of iterations, in favour of more elaborate goals
- The students record limited changes in their digital journals. At best,

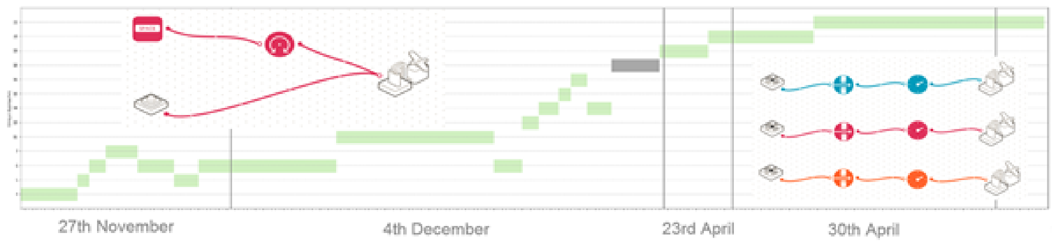


FIGURE 6.26: Student J's Trapdoor Distinct Approaches. Visualisation shows 13 distinct approaches the student iterated through to reach their final design. Number of approaches across the y axis; the project timeline across the x axis. The green bars signify a valid design and the grey bar signifies an invalid design. The top left image displays the intermediate designs as the bars are hovered over, and the bottom right displays the final design for comparison

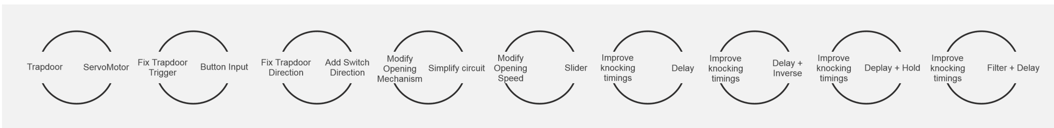


FIGURE 6.27: Student J's Trapdoor Goal-Design Evolution. The 9 circles are linked to the 13 distinct approaches the student took to implement their trapdoor. The left label names the behaviour goal and the right label names the corresponding functionality change to implement the goal. The evolution across 13 approaches highlights the continuous optimisation between students' theoretical goals and their practical implementation, linked to appropriation

they upload a photo and a small explanation at the end of each element's construction, without much elaboration on the way in which the designs were adapted

- The students seem comfortable making changes that do not align with their original intentions as they progress in their constructions
- The students discard a large amount of fully working prototypes that they build, leaving the final artefact reflecting only a small percentage of their experiments

6.2 Emerging Dimensions

Consolidating the version changes within single visualisations allows for reviewing the distinct iterations students go through to complete their designs, and investigating to some extent the nature of the changes. The different ways of visualising changes over time allows for investigating the ways in which students add and remove components and connections, switch

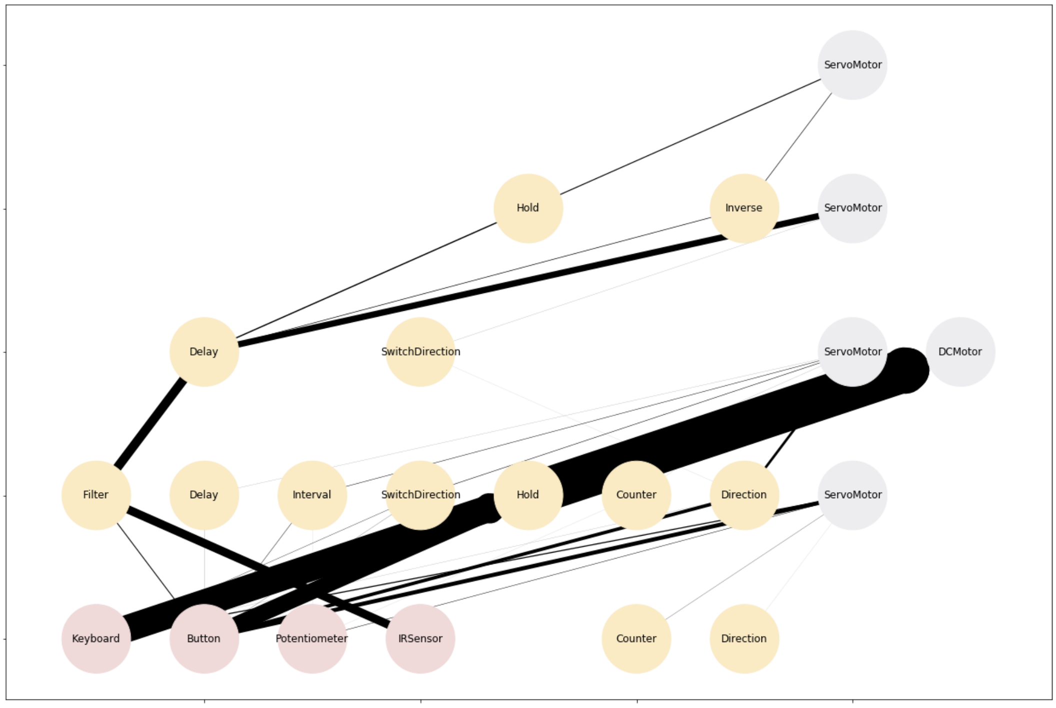


FIGURE 6.28: Student J's Trapdoor Blocks and Connections. The student used a total of 14 blocks connected across 14 circuits to implement their trapdoor. The graph displays the SAM Labs blocks as nodes and the circuit connections as edges between nodes. The width of the edges signifies the number of times the same connection is used across the project timeline. Input blocks are red, connector blocks are yellow and output blocks are blue.

between approaches, use the same blocks and connections across contexts or varying between behaviours within the same context. The information which emerges about the students' iterative designs can be described using three dimensions that cut across all visualisations: variety, validity and complexity. The visualisations expose the variety of approaches, components and connections which students explore, the validity of these attempts, and the complexity based on the number of components or nature of blocks used to implement their designs.

The variety, validity and complexity dimensions represent a simplification of the common threads which emerge from visualising the students' track changes over time, as presented in Section 1. The dimensions serve as descriptors in the context of the students' iterations rather than primary measurements. Equally, the dimensions are present in the visualisations alongside each other, rather than in isolation. This offers teachers the opportunity to study the variety of a student's iterations in the context of their validity

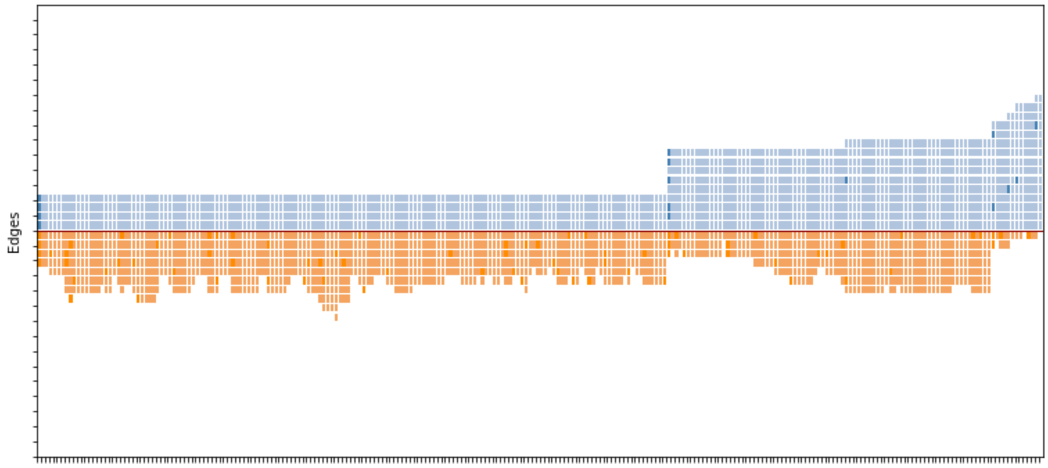


FIGURE 6.29: Student J's Trapdoor Kept versus Discarded. The red line separates the connections between blocks discarded throughout the project below the line from the connections between blocks kept in the final design above the line. Orange marks discarded connections and blue marks kept connections.

and complexity of circuits, or vice-versa, in order to make a qualitative judgment of their work.

6.2.1 Variety

The variety of students' iterations in the context of SAM Labs constructions can be determined by the volume of circuit configurations the students test, as well as how similar or different the tests are between them. This can be visible at different levels, in terms of the different artefacts students think of building with SAM in the first place, the various features they incorporate into each artefact, as well as the different approaches they take to implement each feature. Variety emerges through the distinct SAM components students use during their construction, the different ways in which they connect the components together, as well as the similarity between the components and circuits used.

Conceptually, the variety dimension is used to reflect the spectrum of ideas and experiments students explore during their projects. The variety encompasses the number and nature of solutions generated, which finds pedagogical mappings in similar context across the literature (Radcliffe and Lee, 1989) as an indicator for effective iterative design behaviour: "The possibility for the materials to be used in a variety of ways, and in a variety of complex circumstances, is a hallmark of a designed tinkering experience" (Honey and Kanter, 2013). Variety represents how broadly students think

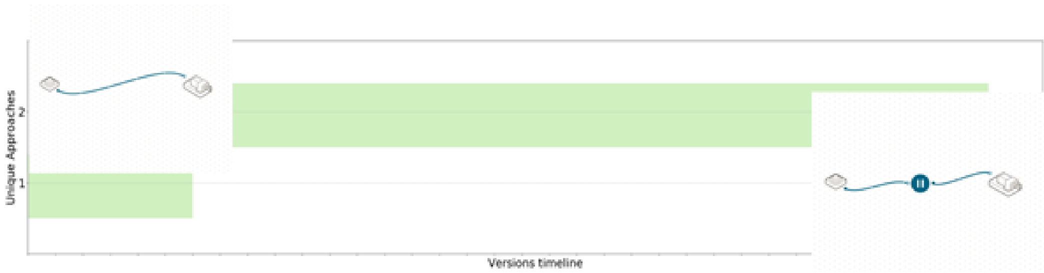


FIGURE 6.30: Student F's Dice Distinct Approaches. Visualisation shows 2 distinct approaches the student iterated through to reach their final design. Number of approaches across the y axis; the project timeline across the x axis. The green bars signify a valid design and the grey bar signifies an invalid design. The top left image displays the intermediate designs as the bars are hovered over, and the bottom right displays the final design for comparison

in terms of the possible different ways in which they can build their SAM Labs constructions. By showing the variety of each project, teachers might be able to better link the degree of exploration students engaged in and the extent to which that served their goal, be that focused on a specific solution or open to possible alternatives.

6.2.2 Validity

Validity represents the accuracy with which students have built their construction in relation to the limits imposed by the SAM Labs functionality. The validity is directly connected to the way in which the SAM kit was designed to work and its rules around how each component is designed to be used. This is irrespective of whether that outcome matched the student's expectation or whether it is indeed aligned with the type of behaviour they are looking to implement. The validity verification includes whether the connections students make abide by the input-connector-output structure every SAM Labs circuit must abide by to produce an output, and whether those components are compatible with each other to affect a consistent, repeatable output. Whilst the SAM components are designed to work in specific ways, they are also built to be connected in flexible ways, allowing different possibilities for connecting the same components in different ways, all valid, but generating different behaviours.

Conceptually, validity is used to reflect the extent to which the students have implemented their behaviours in alignment with the way in which the SAM Labs components are designed to be used. Experimenting with both

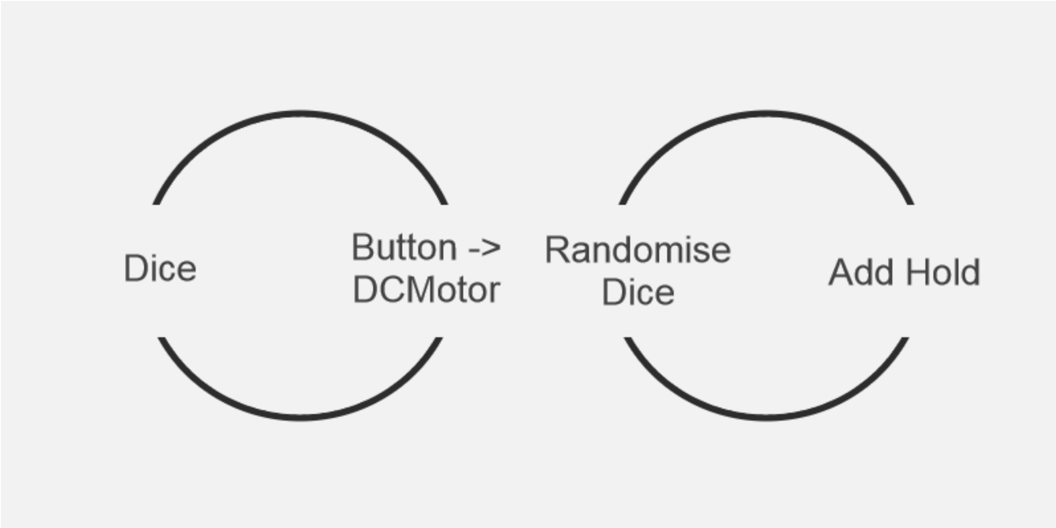


FIGURE 6.31: Student F's Dice Goal-Design Evolution. The 2 circles correlate to the 2 distinct approaches the student took to implement their dice. The left label names the behaviour goal and the right label names the corresponding functionality change to implement the goal. The evolution across 2 approaches highlights the continuous optimisation between students' theoretical goals and their practical implementation, linked to appropriation

valid and invalid circuits is an important part of the students' exploration of the tools' boundaries in different contexts (Gaudiello and Zibetti, 2013). The immediate feedback on execution allows students to quickly identify whether their constructions are valid or not and iterate further. Teachers might be able to observe the type of invalid circuits students construct and decide whether to intervene or not depending on their repetitiveness or the time spent debugging.

6.2.3 Complexity

Complexity represents the difficulty of the design, indicative of the depth and sophistication of the students' construction. Complexity emerges from the nature of the components used, the number of connected blocks in a single circuit, and the number of individual circuits connected in a single graph. Some blocks are more straightforward than others to integrate into a circuit, for example a Button or RGB light are easy to test and frequently used. Other components such as the CodeModule require customisation, cannot be used as they are, can be placed anywhere within a circuit, therefore generating a different functionality each time they are used. A project which uses the code module is more complex than one with a button to

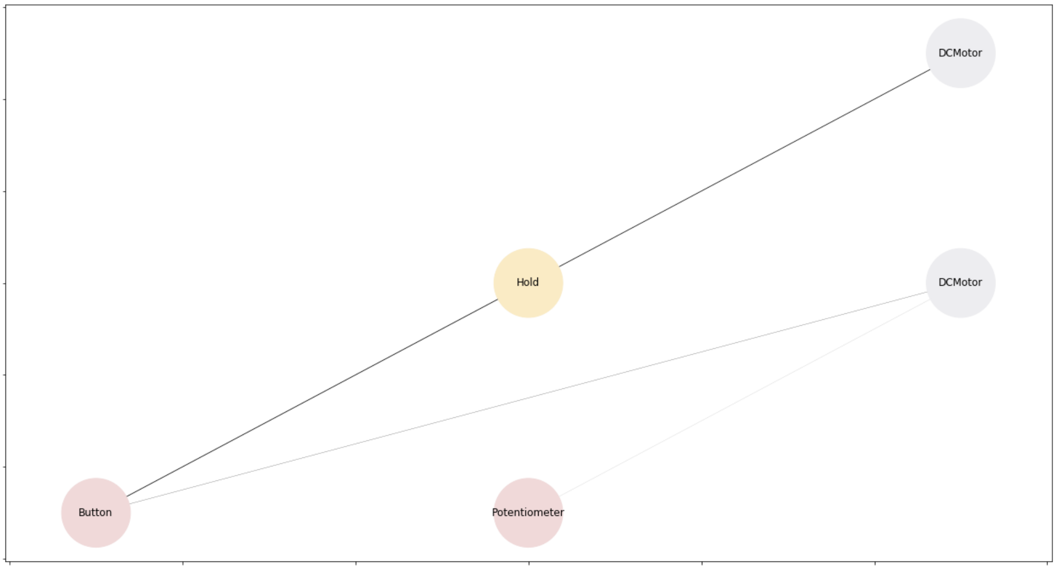


FIGURE 6.32: Student F's Dice Blocks and Connections. The student used a total of 4 blocks connected across 3 circuits to implement their dice. The graph displays the SAM Labs blocks as nodes and the circuit connections as edges between nodes. The width of the edges signifies the number of times the same connection is used across the project timeline. Input blocks are red, connector blocks are yellow and output blocks are blue.

RBG light connection. In addition, a direct circuit between two components will be less complex than a circuit with a connector, and less complex than a circuit with multiple connections.

Conceptually, complexity reflects the extent to which students engage with the individual experiments they conduct of the effects different circuits have on the SAM components in the physical world. A complex construction, if valid, can be indicative of a certain level of mastery of the SAM kit functionality. Complexity is recognised in the design literature as a pedagogical goal, referred to as "opportunities for complexification" (Honey and Kanter, 2013), which challenge and stretch the students' comfort level and understanding (Honey and Kanter, 2013).

6.2.4 Summary

Identifying characteristics such as the validity, variety and complexity of students' iterations might help teachers find a language for describing the students' iterative design work, as well as focusing on specific aspects when scaffolding students' activity. Furthermore, such characteristics might help teachers query the students iterative design work during the reflection process. The relevance of these dimensions for characterising students' iterative design process is further explored with teachers in the evaluation part of the thesis, with the resulting findings presented in Chapter 7.

6.3 Emerging Patterns

From the visualisations of all students' constructions, involving both the code club and board game contexts, emerging patterns are presented below, aligned with design thinking and heuristics searches research.

6.3.1 Heuristic searches: convergent or divergent

The visualisations highlight some of the heuristics (Hayes, 1978) students engage in during their design process. One visible distinction emerges between the convergent and divergent problem-solving strategies students employ at different times during their projects (Barak, 2013). Divergent thinking refers to the generation of multiple answers to a problem, whilst convergent thinking is about exploring the ideas in an in-depth manner (Guilford, 1967). Students alternate between exploring different SAM Labs components that might be suitable for a particular behaviour and homing in those components to refine their outcome.

In the Blocks and Connections visualisations, this distinction is apparent in the distribution between the use of the SAM components across the project. Some students experiment with a higher number of components over shorter iterations, whilst other students use fewer components over longer periods of time. The number of iterations, as well as the distribution of usage between distinct blocks and connections across the iterations, indicate where students experiment with a wide range of components, versus more contained iterations of their designs.

The visualisations in Figures 6.33 and 6.34 exemplify two projects Student N worked on, the buzzer and the trapdoor. The buzzer construction involves little exploration of distinct components, with most of the work going into the CodeModule and Comparator setup. The trapdoor design emerges from testing ten distinct components, choosing between the functionality of the Pressure or Proximity sensors, or the use of the Filter or a CodeModule for manipulating the sensor value.

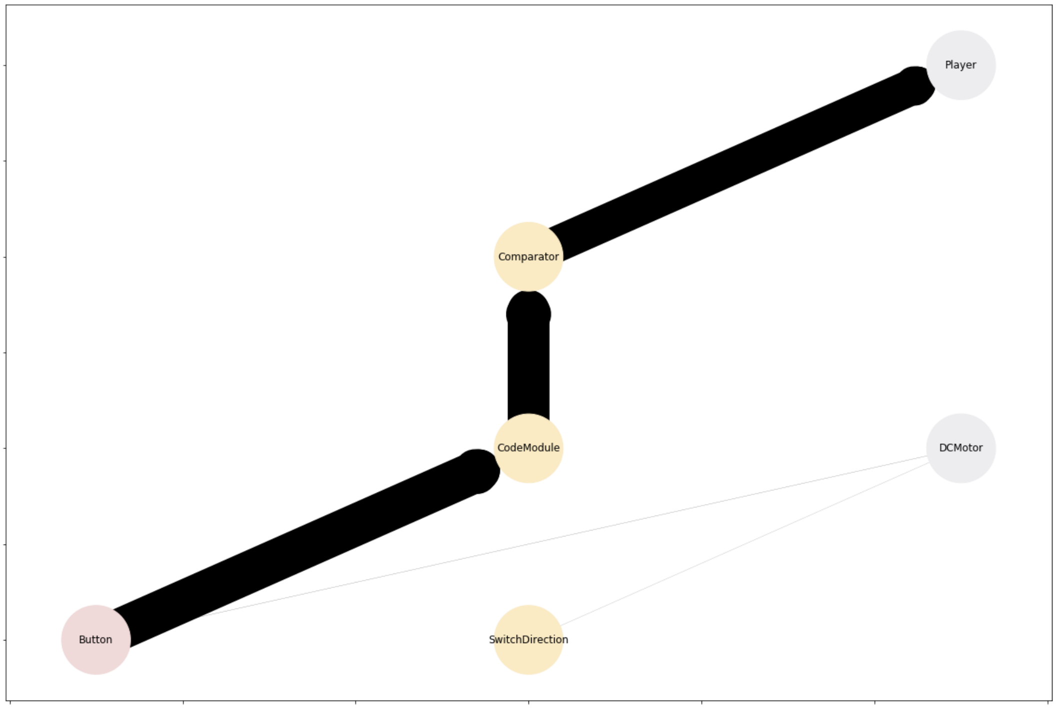


FIGURE 6.33: Blocks and Connections Example of Convergent Design

The same distinction emerges from two of Student A's designs in Figures 6.35 and 6.36: the dice and the trapdoor. For the dice, he quickly narrows down the main circuit also containing the CodeModule and Comparator, and continues to refine their values to generate the desired Player sound. For the trapdoor, he tries eleven different connectors to arrive at a final design.

The number of components, as well as the usage distribution indicated by the width of the connections can point towards more convergent or divergent approaches the students take towards implementing their designs. The visualisation exposes whether students are narrowing down their paths (Barak, 2007), and if so, which ones they are, for a better-informed guided reflection on their search process towards the desired solution. The teachers can use this distinction, in relation to the students' construction goals, to identify whether their efforts are best placed either refining an existing approach or perhaps expanding their search to different components. The visualisations contribute to the growing recognition that iterative design employs both divergent and convergent thinking either simultaneously or alternating between them (Howard-Jones, 2002), rather than sequentially.

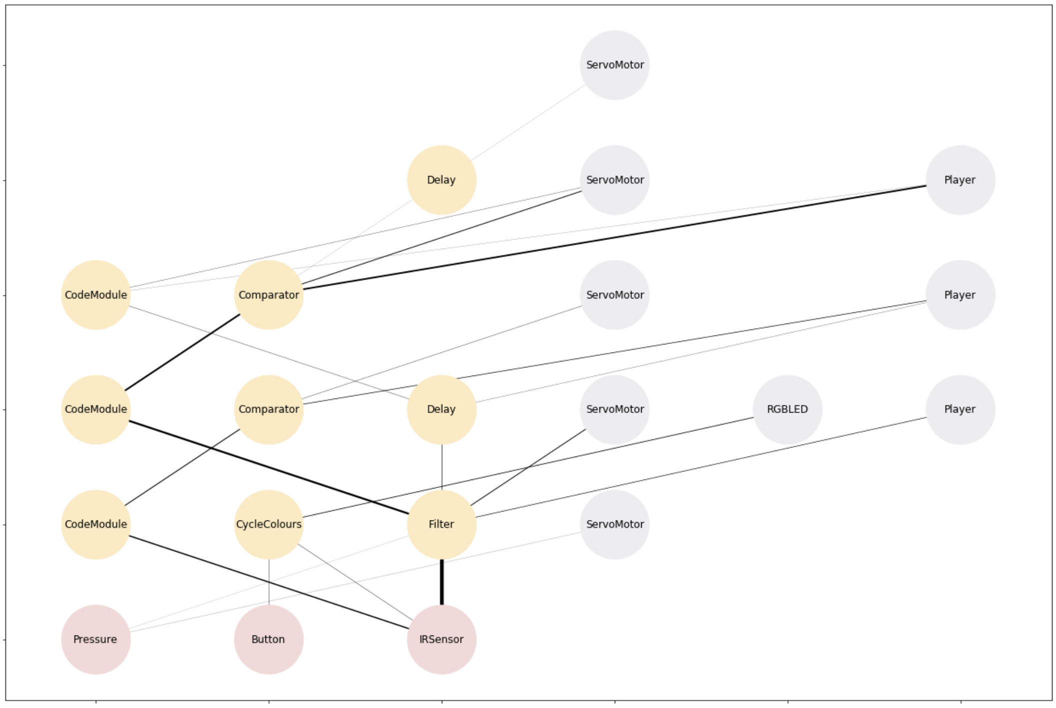


FIGURE 6.34: Blocks and Connections Example of Divergent Design

6.3.2 Volume and timings of discarded work

As identified by Barlex and Welch, the expectation of a serial development towards a final solution put forward by traditional problem-solving sequential models is at odds with the way in which children solve design problems in practice (Barlex and Welch, 2009). Rather than following a sequential pattern of activity, children move from one type of design activity to another, with a final design emerging throughout the design process (Hill and Anning, 2001b; Hill and Anning, 2001a; Johnsey, 1997; Murphy and Hennessy, 2001; Mawson, 2003).

The 'Kept versus Discarded' visualisation exposes both the timings, and the amounts of connections students build and discard during their constructions. Two main patterns emerge from the students in the sample. First, the students consistently discard more connections than they keep. Second, the students start building toward their final solution in the last third part of their available project time, using the first two thirds mostly for experiments that they mostly discard. Four examples are displayed in Figures 6.37, 6.38, 6.39 and 6.40, however the same image emerged from the majority of the student cohort participating in the present research.

Visualising the amount of connections which get discarded in open-ended

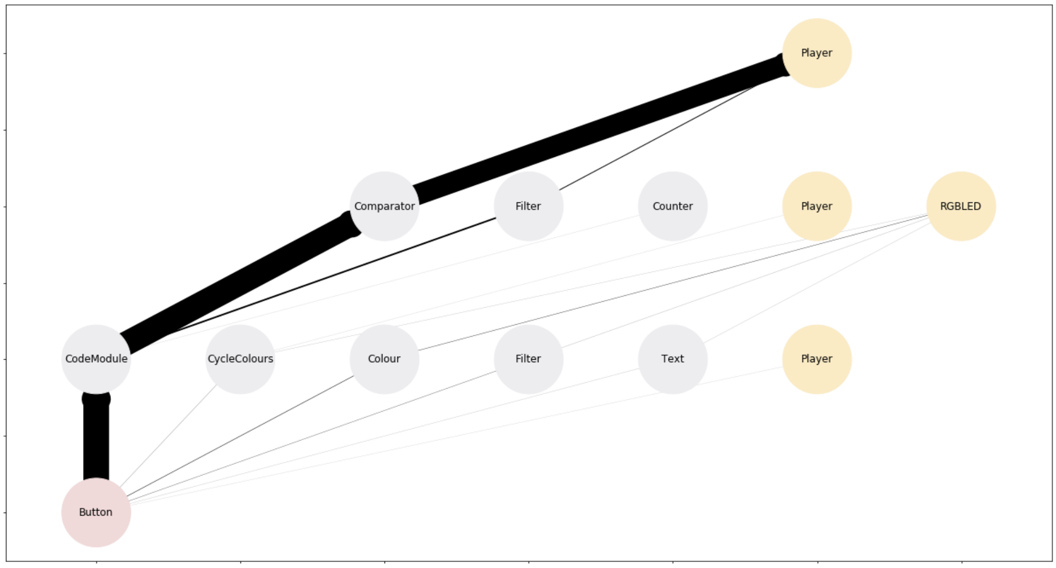


FIGURE 6.35: Blocks and Connections Example of Convergent Design

projects exposes the amount of experimentation which leads to the end outcome. The Kept versus Discarded visualisation also shows the timings in the project when students start contributing directly to their final designs. The students appear to separate between the time they have available to experiment and try out alternatives which they do not intend to keep, and the time during which they build towards their end-product.

6.3.3 Same target behaviours, distinct constructions

In their reflection on design principles of construction kits for children, Resnick and Silverman highlight the diversity amongst students, and the importance of integrating it into the evaluation setup: "When we evaluate the use of our construction kits, we consider diversity of outcomes as an indicator of success. If the creations from a class of students are all similar to one another, we feel that something has gone wrong" (Resnick and Silverman, 2005). The diversity which emerges from open-ended learning experiences using construction kits is a direct result of students having the freedom to use their own experiences to inform their own construction goals. This is observed repeatedly in the context of students building with the SAM Labs kit, and is explored through the Distinct Approaches visualisation. Four students' work implementing the trapdoors for their boardgames are explored from Figures 6.41, 6.42, 6.43 and 6.44. All four constructions target the same functionality: a way of automatically sensing when a player's piece

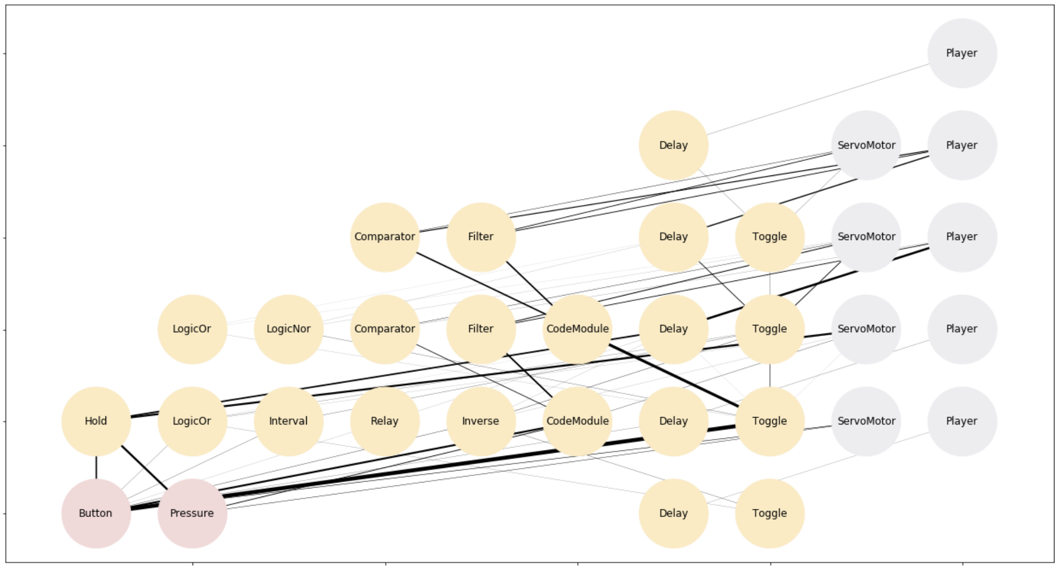


FIGURE 6.36: Blocks and Connections Example of Divergent Design

approaches the trapdoor, and automatically opening the trapdoor consisting of a cut-out square of the pizza board, causing the piece to fall through. The students worked on their projects in the same classroom, aware of each other's constructions. Whilst they were working on their own games independently, they organically collaborated on specific parts of their trapdoors, grouping together to share their findings on either the sensitivity of the servo-motor, or the different ways of keeping the trapdoor open long enough for the piece to fall through.

All four students achieve a complete and valid construction of a trapdoor, all students use a sensor to trigger the trapdoor opening, all students use a servomotor to activate the trapdoor itself, and all students manipulate in some form the timing of when and how long the trapdoor remains open for, to allow enough time for the piece to fall through. However, the final circuits are distinctly different from each other, using different sensors – either proximity or pressure, different timing connectors – either hold or delay in slightly different configurations, and two of the students accompany their trap door action by a sound player. The same variation can be seen for all students in the class who implemented a trapdoor, as well as the other behaviours integrated into the board game such as the dice, a random quiz question generator, or additional distinct behaviours only one or a few students implemented.

The variation exists both in the game behaviours students chose to build,

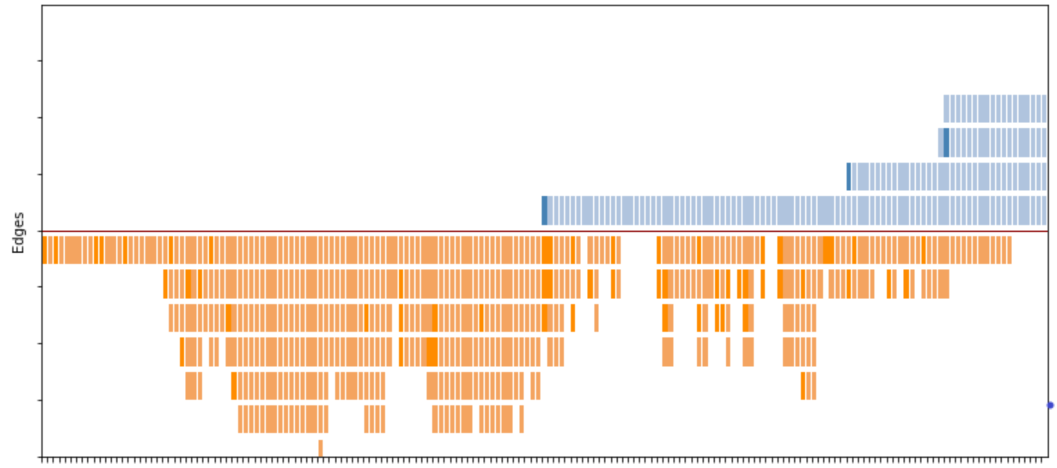


FIGURE 6.37: Kept versus Discarded Student A Trapdoor. The red line separates the connections between blocks discarded throughout the project below the line from the connections between blocks kept in the final design above the line. Orange marks discarded connections and blue marks kept connections.

but also in the way in which they implemented those behaviours, even when these were shared amongst several students. However, the most striking diversity is visible in the process the students engaged in to construct their artefacts. In the example of the four students above, each student displays a different number and variety of approaches taken to reach their final artefact, a different validity pattern of their experiments and differences in the complexity both of their start and end points.

Visualising the distinct approaches students take towards reaching their end-products can help to better question the process by which students reach the diverse outcomes Resnick and Silverman consider an indicator of success. The diversity emerging from the visualisations also concretises Mawson's conclusion that students do not use a predetermined design process, instead repeatedly employing a process of discovery as they advance in their task, informed by each attempt. Critically, Mawson stresses that the solution to a design problem involves more variables than traditionally mapped in problem-solving models, which cannot be expressed through a series of sequential steps (Williams et al., 2000).

6.3.4 Summary

The patterns emerging from the visualisations when compared across multiple students expose some of the pedagogical tensions which arise in open-ended design projects.

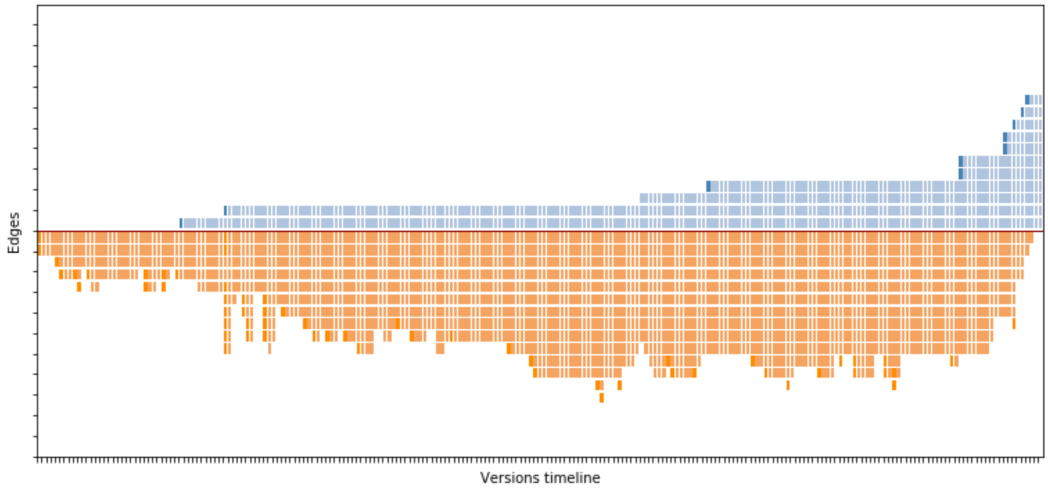


FIGURE 6.38: Kept versus Discarded Student N Car. The red line separates the connections between blocks discarded throughout the project below the line from the connections between blocks kept in the final design above the line. Orange marks discarded connections and blue marks kept connections.

One such tension emerges between the variety of distinct approaches students explore and the consolidation and refinement of a single design. Exploring a variety of components as well as refining a single circuit to best suit expectations present different learning opportunities, and they should both, in balance, present themselves as part of students' constructions. However, as seen from the examples above, these will not always be part of every project for every student, and they will depend on the students' goals and how close a certain design is against expectations. A high degree of variety can be indicative of students' curiosity and ability to generate different ideas for implementing their goals, but it can also be restrictive in terms of how deeply students engage with each idea.

Another tension is identified between the complexity of the students' designs and finding the most appropriate solution to a challenge. Whilst complex designs indicate a good understanding of the SAM Labs functionality, simple designs can be the result of a productive iterative design process where more complex solutions were discarded in favour of equally effective, more simple circuits. Complexity isn't necessarily an indicator for depth of knowledge, with simple solutions often being a more effective route to the construction of specific behaviours. Knowing that the students can correctly implement complex solutions, as well as their ability to simplify them where possible to achieve the same result are both worthwhile goals, depending on what the student is trying to achieve. Yet again, the suitability of a complex

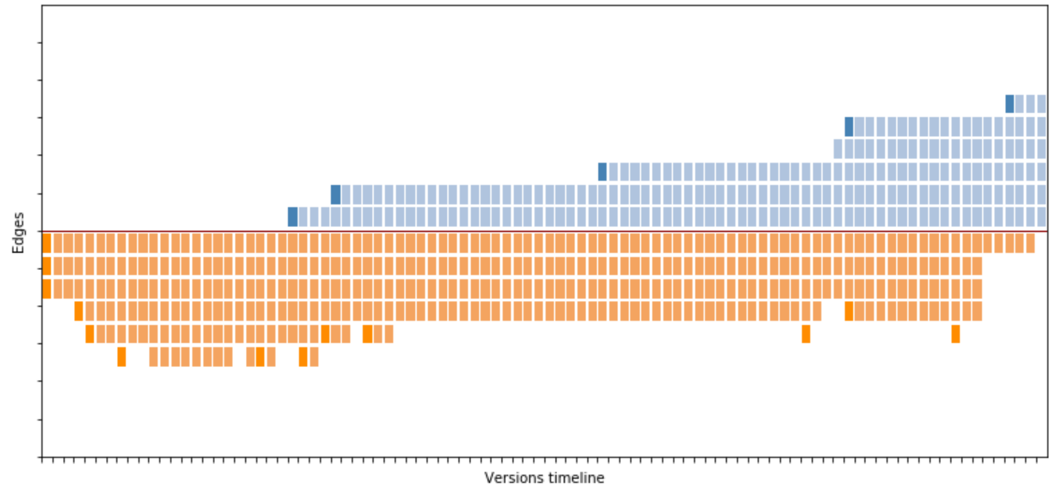


FIGURE 6.39: Kept versus Discarded Student J Sound Effect. The red line separates the connections between blocks discarded throughout the project below the line from the connections between blocks kept in the final design above the line. Orange marks discarded connections and blue marks kept connections.

or simple design is dictated by the students' goals, and the main learning gains will reside in the iterations which led to the final design.

A third tension is presented in the validity analysis of what the students build, between using the SAM Labs components correctly and discovering new ways of using them, which often involves making mistakes. A design which emerges from fully valid iterations might indicate the student has built it using previous knowledge, or systematically followed the SAM Labs construction rules and troubleshooted effectively. A design which entails many invalid iterations might indicate a student is stuck with a misunderstanding or an exposure to the ways in which blocks cannot be used.

The dimensions of variety, validity and complexity sit on a spectrum and change continuously across the activity timeline, in synchrony with the students' intentions and understanding of the actions they are taking. The question of effective iterative design in open-ended settings resides in combining information on dimensions such as variety, validity and complexity with students' intentions, effectively placing the quantitative interpretations of students' actions into the context of what they are trying to achieve.

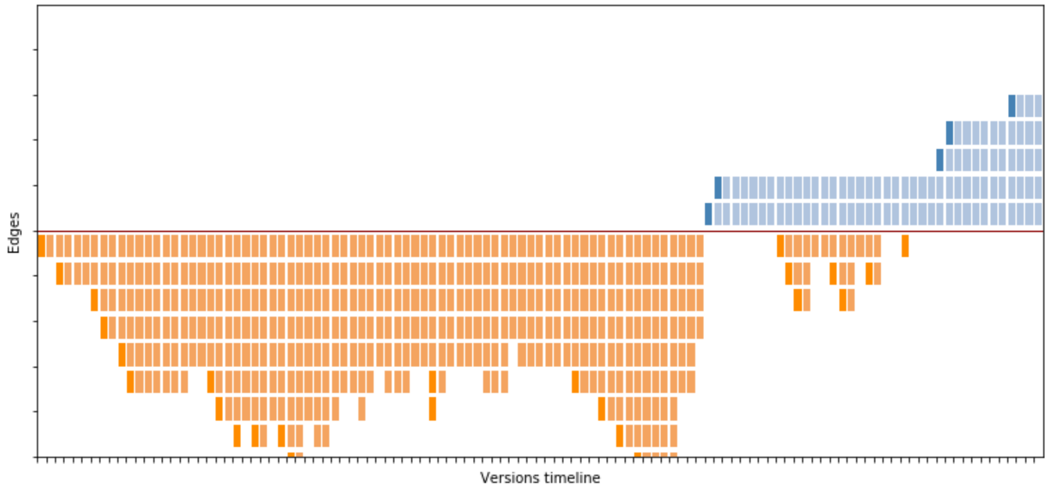


FIGURE 6.40: Kept versus Discarded Student E Light Effect. The red line separates the connections between blocks discarded throughout the project below the line from the connections between blocks kept in the final design above the line. Orange marks discarded connections and blue marks kept connections.

6.4 Conclusion

The analysis presented in this chapter constitutes a subset of representative examples of students' constructions from the board game project, and the way in which the video, audio and digital journaling data can enhance the narrative visible from the data visualisations. The iterative design behaviour activity as observed from the data visualisations, combined with the audio and video data, provides insights into the ways in which students appropriate the SAM Labs kit for their own purposes. The goals students formulate are constantly reformulated in view of what students discover is possible to build with the SAM Labs blocks, and new goals are formed based on newly discovered functionality. Variety, validity and complexity are identified as proxy dimensions used to characterise students' iterative design behaviours. The dimensions are explored in terms of their meaning for students' iterative design process and potential for informing the student-teacher guided reflection process. Finally, patterns of iterative behaviours are identified as they emerge from most students' data, used to describe students' iterative behaviours across cohorts. The data analysis presented in this Chapter 6 points to potential ways the data visualisations might support the exploration of students iterative practices. In Chapter 7, these are validated with teachers. The visualisations were used as objects to think with about students' iterative design and inform their usability and

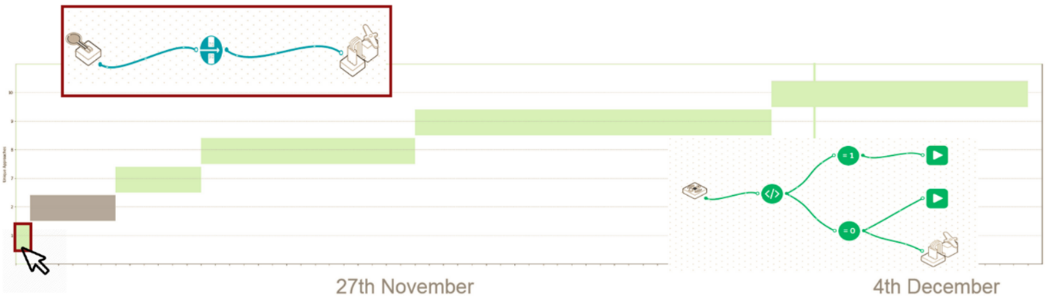


FIGURE 6.41: Distinct Approaches Student N Trapdoor. Visualisation shows 6 distinct approaches the student iterated through to reach their final design. Number of approaches across the y axis; the project timeline across the x axis. The green bars signify a valid design and the grey bar signifies an invalid design. The top left image displays the intermediate designs as the bars are hovered over, and the bottom right displays the final design for comparison

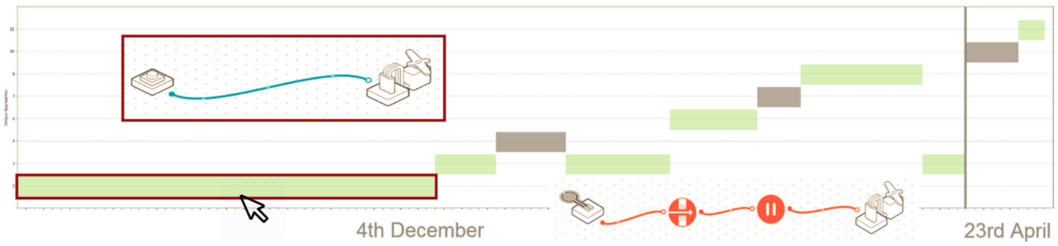


FIGURE 6.42: Distinct Approaches Student E Trapdoor. Visualisation shows 8 distinct approaches the student iterated through to reach their final design. Number of approaches across the y axis; the project timeline across the x axis. The green bars signify a valid design and the grey bar signifies an invalid design. The top left image displays the intermediate designs as the bars are hovered over, and the bottom right displays the final design for comparison

potential to support the student-teacher guided reflection. The evaluation allows teachers to feedback on some of the analysis conducted in the present chapter, and allows for teachers to inform future versions of the visualisations.

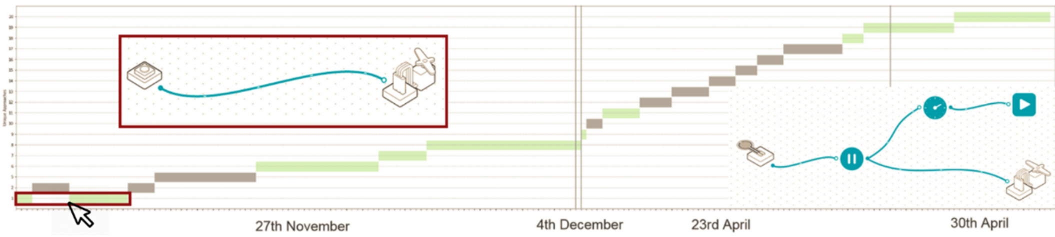


FIGURE 6.43: Distinct Approaches Student A Trapdoor. Visualisation shows 18 distinct approaches the student iterated through to reach their final design. Number of approaches across the y axis; the project timeline across the x axis. The green bars signify a valid design and the grey bar signifies an invalid design. The top left image displays the intermediate designs as the bars are hovered over, and the bottom right displays the final design for comparison

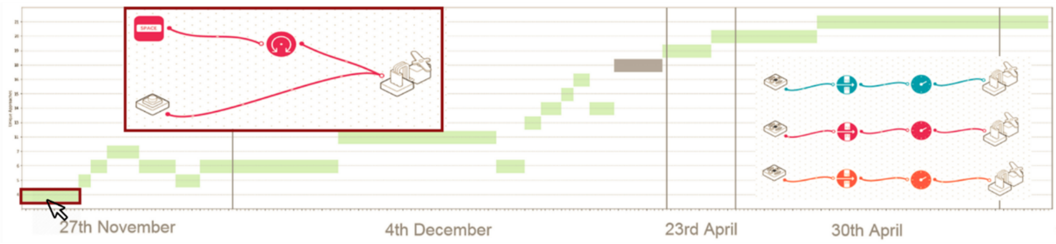


FIGURE 6.44: Distinct Approaches Student J Trapdoor. Visualisation shows 13 distinct approaches the student iterated through to reach their final design. Number of approaches across the y axis; the project timeline across the x axis. The green bars signify a valid design and the grey bar signifies an invalid design. The top left image displays the intermediate designs as the bars are hovered over, and the bottom right displays the final design for comparison

Chapter 7

Teacher Evaluation

Chapter 7 presents an evaluation conducted with teachers to assess the design choices which informed the data visualisations as presented in Chapter 5, and the analysis conducted in Chapter 6. The evaluation focuses on exploring the visualisations' potential to support the student-teacher guided reflection in open-ended construction tasks using physical computing kits. The teacher evaluations were undertaken with the purpose of identifying the ways in which the visualisations adhere to their intended goals, as identified across the first two research phases:

- How do teachers interpret the information in the visualisations and what aspects of the students' iterative design process do the prototypes prompt teachers to discuss in detail?
- What potential do the visualisations hold for supporting the guided reflection between teachers and students aimed at improving students' iterative behaviours?

Ten teachers were interviewed as part of the evaluation stage of the present thesis. All the teachers were familiar with the SAM Labs physical computing kit, had a good understanding of the kit's functionality and they all had experience teaching with it in either late primary or early secondary education stages, the age the kits are targeted at. Specifically, all the teachers had experience designing, supporting, and evaluating open-ended design projects with their students across several weeks. Teachers' prior experience was an important part of the evaluation – the visualisations were specifically designed with the purpose of evoking teachers' understanding and interpretation of the iterative design process students engage in, in open-ended settings. This required a conceptual foundation for the evaluation interviews to be based on, from teachers who already had awareness of the opportunities and challenges open-ended practical learning experiences present. The teachers' knowledge of the SAM Labs kit and their experience designing open-ended projects using it helped focus the interviews on the specific role data visualisations play in such contexts. The teachers were also able to interpret the SAM Labs graphs without detailed explanations of what the blocks were or how they functioned.

An interview script was used to help the researcher structure the interviews and keep them focused on the target evaluation questions. The script was made up of four main parts:

1. The first part explores the teachers' existing experiences of designing and supporting open-ended projects using SAM Labs and other physical computing kits

2. The second part presents a ranking exercise the teachers undertook to analyse and evaluate four students' designs. All four students implemented the same behaviour, a trapdoor, for their board games, therefore providing a comparison basis for teachers' analysis. The teachers were asked to rank the students in sequential order twice, first based solely on the students' final SAM Labs design, and second based on the added information from the Distinct Approaches interactive version of the visualisation

3. The third part explores all four data visualisations from the same four students, and asks teachers to provide feedback on the information conveyed by the visualisation

4. Lastly, the fourth part covers the practical role and potential use of the visualisations in the classroom, as envisaged by the teachers

The interview script is attached in Appendix H. The audio transcriptions from the teachers' interviews are attached in Appendix I. Further details about the focus of each part of the interview is provided at the beginning of each relevant section further in this chapter.

7.1 Social Translucence Framework

The interviews were designed to evaluate the role of data visualisations for analysing and supporting the iterative design process students engage in, in open-ended settings. The teachers' feedback is structured around the three social translucence principles of visibility, awareness and accountability (Erickson and Kellogg, 2000). The social translucence approach was developed by Erickson and Kellogg to address the lack of visibility, awareness or accountability of digital activity in the design of computer-mediated systems (Erickson and Kellogg, 2000). Their approach outlines steps to "design digital systems that support coherent behavior by making participants and their activities visible to one another" (Erickson and Kellogg, 2000). Their proposed goals align with the intentions of the data visualisations developed as part of this thesis research, of making students' actions more visible so that can be analysed by teachers in a meaningful way. Therefore, the social translucence principles are used to analyse the interview answers to examine the ways in which the data visualisations contribute to the visibility, awareness and accountability of the students' digital trace of using physical computing kits, as interpreted by teachers. The interview answers were analysed according to whether the feedback contributed to the visibility, awareness or accountability principle, as defined by Erickson and Kellogg, 2000, and presented across the three themes.

Prestigiacomo et. al use the concept of translucence to design a human-centred approach to understand teachers' learning data needs (Prestigiacomo et al., 2020). They highlight the lack of human-centred methodological approaches available to engage with teachers and learners in the design of learning analytics systems. In response, they use the notion of translucence to operationalise an approach of designing LA systems with students and teachers. They identify steps that other researchers or designers can use to structure participatory sessions to understand the data needs stakeholders have and build around those (Prestigiacomo et al., 2020). Echeverria et. al also use social translucence in combination with quantitative ethnography to analyse multi-modal group activity data in the context of collaborative work during nursing simulations (Echeverria, Martinez-Maldonado, and Buckingham Shum, 2019). Their approach is intended to address the disconnect between logged data and higher order educational constructs. They use the social translucence concept to give meaning to data in a way that accounts for challenges encountered by learning analytics designers. This includes the instrinsic incompleteness of any data set, the differences between contexts in which activities unfold and the complexity of learning experiences that involve higher order thinking, non-computer mediated interactions, or ill-defined, open tasks (Echeverria, Martinez-Maldonado, and Buckingham Shum, 2019), all of which are applicable to SAM Labs learning

TABLE 7.1: Summary of teacher interview's objectives and social translucence mapping

	Objective	Approach	Social Translucence
Part 1	Teachers' background	Semi-structured questions	
Part 2	Impact of iterations on interpreting students' designs	Ranking Exercise	Visibility and Awareness
Part 3	Visualisations' interpretation	Semi-structured questions	Visibility and Awareness
Part 4	Potential use of visualisations in the classroom	Semi-structured questions	Accountability

environments.

Most studies have only used the social translucence approach to consider quantitative face-to-face or online social aspects (Kim et al., 2008; DiMicco et al., 2007; Bachour, Kaplan, and Dillenbourg, 2010). This is despite the designers' original vision for the social translucence approach to be applied for modelling complex traits of group behaviours or tracking and visualising social behaviours over time (Erickson and Kellogg, 2000). The social translucence approach is particularly applicable for the study of complex face-to-face situations enriched by digital technologies, where the physical and virtual activities merge in a unified experience (Niemantsverdriet et al., 2016; Bilandzic and Foth, 2012). This makes social translucence especially appropriate for the analysis of contexts where students learn using physical computing kits like SAM Labs, that translate virtual actions of connecting components into real-world behaviours of the physical artefacts.

The way in which the four parts of the interview and their objectives match the social translucence dimensions is summarised in Table 7.1.

Below we present the results from the analysis of the interviews. First, we present the participating teachers' background that was explored in the first part of the interview, as well as aspects of their experience teaching in open-ended contexts using physical computing kits. Second, we outline the outcomes of an investigation making up the second part of the interview, designed to frame the conversation around the students' iterative process. The investigation entails teachers judging four students' constructions based on two different sets of information. The first is solely based on the students' final SAM Labs design, and a second is based on added information on the students' iterative design activity as it emerges from the Distinct Approaches visualisation. The third Results section presents the outcomes of both the third and fourth parts of the interview, where the teachers' feedback of the data visualisations is presented based on the social translucence dimensions of visibility, awareness and accountability (Erickson and Kellogg, 2000).

7.2 Teachers' background and existing experience

In this section, we present the teachers' responses to the questions in the first part of the interview. The first part of the interview focused on the teachers' background and previous experience designing and evaluating open-ended projects using physical computing kits. The questions revolved around the teachers' motivations for engaging their students in open-ended practical learning experiences, and their observations and challenges in such environments.

All the participants' teaching roles were related to teaching technology, robotics, coding or computer science in their schools. Seven taught at primary school level, seven at secondary school level, and one teacher covered both primary and secondary technology teaching. The exact subjects and ages the teachers taught varied between them, depending on their role and school structure, however they all had experience with using SAM Labs with children between the ages of 8 to 12 in open-ended projects. The participants' teaching roles are listed below:

1. Teacher A – Primary and Secondary Technology Education Coordinator
2. Teacher B – Secondary Design Teacher and FabLab Co-Manager
3. Teacher C – Primary Teacher, PAECT ISTE Representative
4. Teacher D – Secondary Maths, Physics and Engineering Teacher, Robotics Philadelphia Team Leader
5. Teacher E – Primary Instructional Coach, Co-Leader of Innovation Lab
6. Teacher F – Secondary Robotics, Game Design, Programming and IB Computer Science Teacher

7. Teacher G – Secondary Technology Education and Advancement Co-ordinator
8. Teacher H – Primary Teacher, Technology Integration Leader
9. Teacher I – Secondary Computer Science Teacher, FabLab Co-Manager
10. Teacher J – Primary Director of Digital Learning, Computing and Technology Design Teacher

7.2.1 Teachers' motivations for designing open-ended projects using physical computing kits

When discussing the scope of their teaching role, and the ways in which tools like SAM Labs support those roles, the teachers quickly pointed to the open-ended, practical uses of the physical computing kits. For five teachers, their current practices were rooted in extracurricular experiences, such as teaching in summer camps, running code clubs, or setting up innovation laboratories. They presented these as spaces where students could use the tools in an experimental way, free from narrow assessment, and aligned with the students' interests. Illustrative quotes are:

Teacher A: "non-profit camp called Tinker Camp. It was really a space to get students to use lots of different materials and tools to answer questions and think about the world".

Teacher E: "With the innovation lab we created environments for students to be able to design, create and build, explore, go through that design model in real life, take things into that higher level beyond exams".

All ten teachers commented, in some form, on the importance of using the physical computing kits in open-ended learning experiences. Illustrative quotes are:

Teacher A: "I had this growing interest of how to use technology specifically in the context of open-ended experiences for children"

Teacher C: "This type of projects is needed in schools to be providing students with these type of open-ended opportunities"

Teacher G: "I decided to approach it from the art side of things. You're going to basically be given a task to create some type of interactive piece. It was very open-ended. I really wanted to move away from just staring at screens and get them 'how can I get this to be doing things in a real world?'"

Expanding on the specific benefits they aim to leverage by designing open-ended projects using physical computing kits, the teachers turned to aspects of motivation, curiosity, creativity and problem-solving.

Teacher A: "What would be a way to get the kids interested?"

Teacher E: "Our school test scores are really high, but we were looking at what we can do to go beyond and push the students further. So, we looked at things around innovation mindset, we turned to the 'Innovate Inside the Box' book, and we thought about how we can integrate technology into our curriculum and how can we do it seamlessly".

The iterative design process which children get to practice in open-ended practical projects was highlighted by all teachers. The teachers referred to these in different terms: experimentation, iterative thinking, design process or trial-and-error. Example quotes are:

Teacher B: "I liked that the second student <in the context video> was talking about this sword as a test. So already they are thinking iteratively, like 'I've got to test that, and then if it works I'm going to move onto the next step.' That was kinda cool, the second student did that specifically."

Teacher C: "I think it's important to strategically share with students the design process. I think it would have been good for the teacher to bring in someone who is already an engineer, who designs things. Because as soon as you collaborate with someone who does it for a living, you realise the value of trial-and-error. You realise that's the most important part that you're working through."

Teacher D: "How to conduct an experiment, or how to troubleshoot, they're content, they are disciplinary content 'how designers work', or 'how an engineer works' or 'how mathematicians work'. The hard content or the soft content are learning objectives. I'm going to start from there. That's where my criteria starts from and then I'm going to figure out how I'm going to get them to demonstrate it in a project."

Five teachers emphasised the link between iterations and effort, trying to nurture a culture of hard work above perfect end-products. Two example quotes:

Teacher F: "It's all a matter of effort and persistence. You can get this. This thing called the academic mindset, beliefs that students need to come into a class holding in order to achieve success."

Teacher D: "I often approach problems from an engineering perspective. So, you have limited materials, or an ill-defined problem, or a situation ... here are the constraints that you have. And you need to show that through experimentation, and that it does it repeatedly."

Teacher A also pointed out to the importance of the way in which learning experiences and tools are designed to promote such iterative behaviours: *"Scratch is so well-designed for exploration that I didn't have to do much teaching. I used MBots, and then Swift - The kids didn't have much opportunity to get very open-ended, they really had to get through this gamified path. With SAM Labs, I was taken by its potential in terms of programming to make almost anything. So that was really exciting for me."*

7.2.2 Documenting the iterative design process

Teachers were also asked about their current practices around getting students to document their work in such open-ended contexts. Whilst acknowledging the importance of on-going documentation to support their experimentation process, it was difficult for all teachers to clearly articulate the type of documentation which would be most useful for students to present in these contexts, with Teacher A admitting: *"I didn't really document per se. I don't do any collection of very hard solid data. My projects haven't been long enough or deep enough to feel like I could do any strong evaluation of growth"*. Teachers B, C, D and F specifically mentioned structuring their requirements for students to document using a design thinking cycle and the importance of getting students to evidence their work-in-progress for assessment:

Teacher C: "When my students present, they have to present in terms of the design process. These are the initial sketches, this was our prototype, this is what happened when we tried it, this is how we changed it, and this is where we are now. The students are not just saying 'I created this, this is what I made', but 'I worked through this process. Here is step by step how I did it.' They're creating this presentation knowing that at the end of the project they will share with everyone and know that 'They don't want to know what I made, they want to know the process behind how I created this, they want to know about my journey'."

Teacher D: "I want them to have evidence that they've achieved the criteria. Not only to achieve the criteria, but also make the clear case that they've achieved that criteria. That's the communication of the content, communicating like a designer or engineer."

Teacher F: "The completion of their notebooks is more important than the completion of their projects. I expect that to have video, pictures, coding examples. I also have quizzes throughout the project but the notebooks are weighted more heavily than the quizzes are. A lot of their engineering notebooks include things that say 'I didn't accomplish what was set out for me, and I learnt this in trying it, but I didn't understand this other thing' and they don't lose any points for saying that."

Five teachers also commented on the format of the students' documentation, and the affordances of digital journaling as a way of allowing students to document in the format best suited to the design work and maintaining a historical record of students' actions to help them continue working on their projects:

Teacher C :"I like that she had time for them to document their changes along the way. I know that for my own students they do not always enjoy the reflection aspect of it. But if I provide options besides just writing, like reporting the changes and talk about it along the way, then I see more responses from students that really engage in the process but might be more reluctant to document. So, I like that she allowed them to take pictures etc along the way. And I like that she focused on the changes to the project too".

Teacher H: "To get a good record of what kids had done, we've been using a lot of videos. And I go back and watch them, to see kind of what they were thinking, even if I'm not able to check in with each kid as they go. Which has been really helpful"

Teacher B: "There are also those students who need a lot of guidance. For us, the best way to support them is get them to review their previous work. Show what you did before, and we'll go from there. That seems to work well with open-ended questions."

The teachers also talked through some of the challenges they face in trying to promote and nurture the learning environments they are aiming for with open-ended projects using physical computing kits. The comments revolved around the difficulty in getting students to accept work in progress and failures.

Teacher F: "Because it's a private school, there's a pressure to always be high end, that students don't want to show they don't know how to do something. But the SAM Labs itself allowed for this playfulness that the other computational tools did not. So how do I then, when they get to that sticky point, bring about a sense of curiosity?"

Teacher B: "And it's hard. I think the kids are used to having something that works, and if it doesn't work, they don't know what to do next. That's the biggest thing for us: documentation and re-visiting what you've done before and making decisions based on previous experience. That works for any project, that's universal, that works for an essay, for a science project, for any piece of work. But it's a tough sell. Kids have a hard time understanding that."

7.2.3 Summary

Several distinct aspects can be identified in the teachers' motivations for engaging their students in open-ended projects using the SAM Labs physical computing kits. The teachers' reported background experience points to a hierarchy of learning objectives being targeted when designing open-ended projects using physical computing kits. The teachers highlighted in equal measure the computing constructs they target in the design of their projects alongside the open-ended, practical way in which students interact with the target constructs. From a learning analytics perspective, it is important to reflect the teachers' objectives and priorities in the analytics and visualisations, rather than a subset of those easiest to measure and disseminate. However, the teachers' answers also point to the complexities of doing so. When describing their goals, teachers use high-level terms such as interest, motivation, iterations, curiosity and mindset interchangeably, without precise definitions. In addition, despite a clear prioritisation of learning objectives related to the students' iterative design behaviours, a lack of structure emerges in terms of tracking and evaluating these aspects.

7.3 Ranking students based on final solutions versus iteration data

This section presents the teachers' answers from the second part of the interview, where they were asked to compare two different views of the students' project work. To provide background for the interpretation, at the start of the second script section the teachers were presented with a context video which framed the classroom project and gave examples of three students presenting their work.

The teachers were first asked to rank four different students' final SAM designs, and second to re-rank the four students based on additional information on the students' iterative design activity as shown in the Distinct Approaches visualisation. The ranking does not intend to replicate a typical teacher evaluation but to expose the teachers' thinking around the differences between judging a final design and consider the multiple iterations students go through to reach that final design. Therefore, the rankings given by the teachers do not represent a gold standard of student performance evaluation, but a trigger to discuss the implications of introducing information about the students' iterations into the teachers' interpretation of their performance.

7.3.1 Ranking based on final solutions

First, the teachers were presented with the final graphs from four students who participated in the board game project, as seen in Figure 7.1. The SAM Labs designs represent their construction of a mechanical trap door, built to knock a player's piece off the board with a small 3D printed axe, activated by a ServoMotor. The trapdoor represented a comparative example the teachers were able to compare between multiple students for the evaluation purposes.

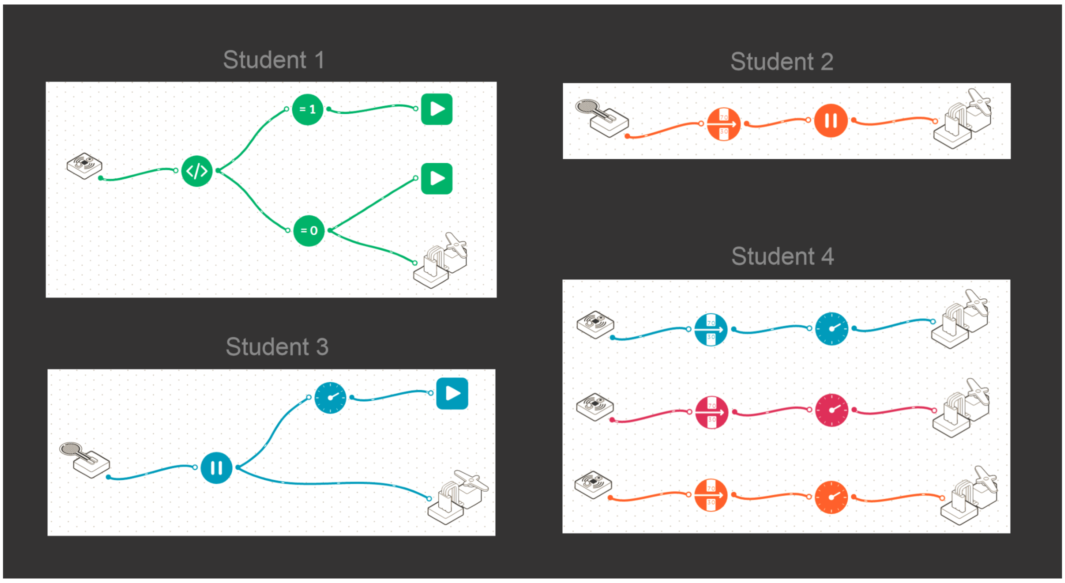


FIGURE 7.1: Ranking Exercise Final Designs

The teachers were asked to rank the final designs of the trap doors from the four students in relation to each other. The teachers were intentionally

TABLE 7.2: Teachers' ranking of students' final designs

Teacher	Final Graph Ranking
A	1,3,4,2
B	1,3,4,2
C	1,3,4,2
D	1,4,2,3
E	1,3,4,2
F	1,3,4,2
G	1,3,4,2
H	1,3,4,2
I	1,3,4,2
J	1,3,4,2

not given ranking criteria, in order to elicit the features they find relevant to evaluate a SAM Labs design.

Nine out of ten teachers ranked the students in this order: Student 1, Student 3, Student 4 and Student 2. The teachers converged on ranking them in terms of complexity of the SAM Labs design from a computing perspective, which explains the high consistency between their answers. When comparing the four solutions, the teachers pointed out differences they based their ranking on. The aspects identified in the answers: complexity, variety, user experience, and conditional logic point to the evaluation aspects teachers look for when interpreting a SAM Labs design. These aspects stand in contrast with the teachers' description of Students 2 and 4's designs: simple, limited, of little value.

Table 7.3 shows the comments per student.

In addition, most teachers followed up their ranking with additional comments around what other factors might influence the interpretation of the four SAM Labs designs, which are not visible from the final designs. They identify two main factors that they would factor into their decision, in addition to the SAM Labs design: knowing the problem the students are trying to solve in their designs and the process the students might have taken to get there. Indicative quotes are:

Teacher C: "I think student 2 probably had a very straightforward solution to the problem they had. I don't really know if that student had to go through a lot of revisions in the process of developing that strategy."

TABLE 7.3: Summary of the teachers' comments per students' final SAM Labs designs

Student 1	**Student 2**	**Student 3**	**Student 4**
Student 1 has the most complex design because of the condition	The simplest is student 2	Students 1 and 3 are complex in their thinking	4 implemented <what student 2 did> 3 times
I am drawn to solution 1, because they are using a conditional statement	Students 2 and 4 are very simple	Students 1 and 3 have a better understanding of key components	Number 4 is very limited, just one circuit.
Student 1 has more varied connections	Number 2 is very limited, just one circuit	Student 3 is doing higher level work	Student 4's design has no greater value than student 2
Student 1 is the best because they have 2 different pathways of logic	Student 4's design has no greater value than student 2	Students 1 and 3 are thinking about the user	
Student 1 has a choice, which might show a little more ingenuity		Student 3 is thinking about the user's experience	

Teacher E: "There's positives and negatives for all of them. Student 4's more efficient than student 1, but student 1 is able to create things that involve 'if you do this, then you get this' <conditional>. I guess it's a decision about game play. I don't know which is better. Student 2 and 4 are saying, 'in case it's not near, don't do anything', which is also fine."

Teacher F: "... whether that's the best thing to do for the game that's a different question, and we'd need to look separately at that" or "If you're aiming to complete the game faster, student 4 is fine."

Teacher D: "I don't know what would be better, if it's the pressure, or proximity, for the game. So, this brings back the point of that, I think it's why the design is so important. You want the students to articulate how they game is going to be played before they start making this circuit and the code."

Whilst ranking the four students' final SAM Labs designs, teachers identified aspects of computing knowledge, user experience, process and alignment with the students' game mechanic goals as relevant aspects. The exercise was intentionally set out to uncover some of the information teachers might be looking for when interpreting SAM Labs designs. The next part of the ranking exercise was designed to provide, at least partially, some of the missing information teachers identified in the first part and to generate comments on the ways in which it either changes or further informs their thinking around the students' iterative behaviours.

7.3.2 Re-ranking based on Distinct Approaches visualisations

Next, the teachers were asked to analyse the Distinct Approaches visualisation presented in the previous chapter for the same four students. The teachers had access to both a static comparative view of all four students, as shown in Figure 7.2, as well as the interactive versions which revealed the SAM Labs design iteration corresponding to each horizontal bar, for each student, available at:

- Student 1: `https://i7zjo1.axshare.com/#c=2`
- Student 2: `https://oidwbb.axshare.com/home.html`
- Student 3: `https://b3qxre.axshare.com/#c=2`
- Student 4: `https://vru9mg.axshare.com/home.html`

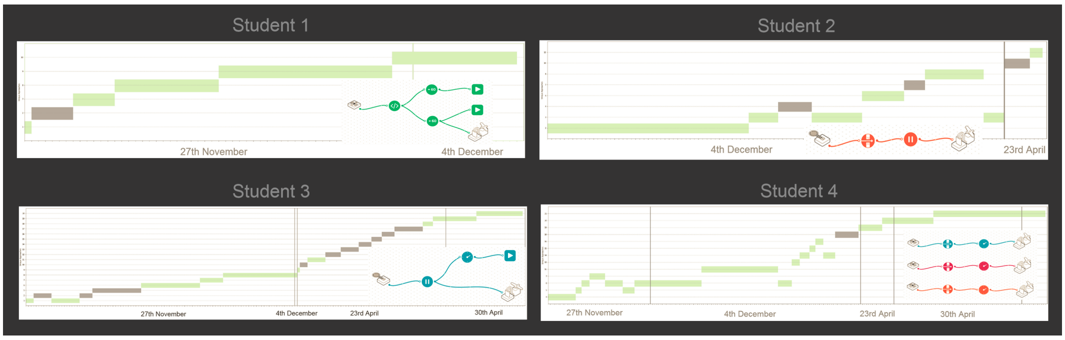


FIGURE 7.2: Ranking Exercise Distinct Approaches

TABLE 7.4: Teachers' re-ranking of students' with Distinct Approaches visualisation

Teacher	Final Graph Ranking	Re-Ranking
A	1,3,4,2	3,4,2,1
B	1,3,4,2	3,1,2,4
C	1,3,4,2	3,4,1,2
D	1,4,2,3	1,4,2,3
E	1,3,4,2	1,3,4,2
F	1,3,4,2	3,4,2,1
G	1,3,4,2	3,1,4,2
H	1,3,4,2	4,3,2,1
I	1,3,4,2	3,4,1,2
J	1,3,4,2	3,4,2,1

The teachers were asked to re-rank the four students, if they thought necessary, after seeing the additional information available from the interactive version of the Distinct Approaches visualisation. Two out of the ten teachers kept their ranking the same. Both Teacher E *"I don't necessarily know that I would change the ranking, in looking at graph number 2, but I definitely got more information about it"* and Teacher D: *"I wouldn't change the ranking, but now I've got this tool to help me understand their design decisions, which is great"* pointed to the fact that, whilst they wouldn't necessarily change the order in which they originally placed the students, they both felt they had more information to base their decision on.

The re-ranking after seeing the Distinct Approaches visualisations is summarised in Table 7.4.

The majority of teachers, eight out of ten, did adjust their ranking, based on the additional information seen in the data visualisation. All but two teachers moved student 3 to higher in the ranking, making student number 3 ranking highest for most teachers. All but two teachers moved student 4 higher as well, which resulted in student number 1 being downranked by all eight teachers who changed their order. Finally, student 2 was up-ranked by five teachers, and kept in the same place by five teachers. The details are presented in Table 7.4.

The final ranking order of the four students is no longer as consistent between the ten teachers as the ranking based just on the final designs. The teachers do not converge around a single way of ordering the four students, however the same upward or downward changes of the same students are seen across the majority. Yet again, the re-ranking exercise is not intended to mimic a typical evaluation process. The purpose of the re-ranking was to identify whether seeing information on the students' iterations changed at all the teachers' view of how the students performed in relation to each other, as well as investigating the reasons why.

The teachers commented on the reasons for their ranking changes mostly in terms of the process they perceived the students to have gone through, based on the iterations visible in the visualisations. The different characteristics teachers describe the process by involve progression, amount accomplished, number of iterations or degree of exploration.

Teacher C: "I might change the ranking of 4, and making it higher than initially thought. Because if I just look at the final product to me it looks like, what I initially saw, without seeing the fact that this student really was working a lot through the process; that would really add a lot of value to their project."

Teacher H: "Because it might not be the best final product, but for that student, to see their thinking, it would change my perspective of what I think that they accomplished with their time. 1 seems pretty steady in their progress, but I feel like now 3 really stands out."

Teacher A: "It totally changes... if I look at it that way, it obviously completely changes my view on student 4. My interpretation of that is that they were trying a bunch of different things, being more exploratory, possibly being more inventive."

7.4 Visualisations Evaluation

This section presents the teachers' understanding and interpretation of the information presented in each data visualisation. Their feedback is framed within the social translucence dimensions of visibility, awareness and accountability, in an attempt to position the role of the visualisations within these parameters. Therefore, we evaluate if and how each data visualisations offers visibility, awareness and accountability of students' digital activity emerging from their SAM Labs designs, recorded in the trace data. The visualisations follow the same four students and the data emerging from their design of the trap door within the context of the board game project. The teachers were presented with each visualisation and given the opportunity to comment on each in turn. The teachers were provided with a matter-of-fact explanation of what the data represented in terms of information across the x and y axis, the meaning of the colors and any further relevant SAM-specific contextual details when requested by the teachers. However, the descriptions did not contain any leading information about what any of the data might signify. For example, the Blocks and Connections visualisation description outlined the meaning of the circles as SAM components used throughout the project, the lines as connections between components, the colours differentiating between type of component: input, connector or output, and the width of the connections as the number of times used across experiments. However, the description did not detail the variety, validity and complexity activity descriptors which were used in the design process, nor go any further to interpret in any way the significance of the data in relation to the students' behaviours or goals.

7.4.1 Visibility

The visibility dimension of the social translucence framework refers to what is made visible by the visualisations. We report on the teachers' feedback of what they see in each data visualisation, independent of what they interpret that to mean or the way in which they would use that information themselves. The results are presented below for each data visualisation in turn.

Distinct Approaches

When describing what they see in the Distinct Approaches visualisations explored through Figure 7.2 and their interactive counterparts, the teachers discussed three main aspects:

- volume and variety of iterations visible through the horizontal bars

- the complexity of iterations as interpreted from hovering over the individual iteration design
- the validity of iterations represented via the green or grey colouring

Teachers associate the visualisation with what students tried, describing them as "a stream of consciousness", "progression", "trial-and-error", "students' thinking", "process", "changes" and "workings". The term "progression" is referred to by five different teachers, even if when presented with the visualisation, the interviewer explicitly clarified that the horizontal bars have no correlation to any progression of the iterations, but simply constitute different complete SAM Labs designs the students used to implement their trap doors. Illustrative quotes are:

Teacher C: "I think it shows the process, I think it shows their revision of changes. It's interesting, it's very clear, when you look at it that way, how students are progressing. This information is very useful to be able to see what the students are working through and thinking along the way. I think that's really helpful. You can see, in time, these shifts in their thinking".

Teacher D: "Yeah, I think it's very interesting to see this progression, absolutely. I'm seeing a lot of trial-and-error, a lot of 'try this, see if it does what I want it to do, and then try this, oh it doesn't do what I want to do, I'll try this thing, oh it still doesn't do what I want it to do, let me go try this other thing, oh now it does it what i want it to do...' So.. i don't know, if feels like there's a lot of trial-and-error, putting blocks in and trying out different things until they work. So I'm seeing trial-and-error. This shows why you want to give the students the tools to test, make decisions based on data, and then move on to the best design and give their rationale as they move through the steps."

Teacher H: "I love this interactive version, I can see each different version and how long they sat with that idea".

The teachers went on to comment on individual students. Eight teachers commented on Student 1 in relation to them having ranked them first initially, only to downgrade them later. The teachers noted the discrepancy between the complexity of the final design and the low number of approaches the student iterates through in comparison with the other students. Example comments:

Teacher A: "Whereas Student 1 and 2, especially Student 1 is .. they've got a few things and then just kinda stuck with it. Maybe they're already really good at this, *and it was not so difficult because they already had a bunch of skills and it was kinda like they knew what they wanted, and they went for it, and they figured it out over time"*

Teacher F: "Student 1, who I initially ranked the highest, seems to have done the least amount of changes."

Teacher G: "So look at the time for student 1, it's gradually consistent as they are progressing with the harder schematic. Time is increasing."

On student 2, the teachers observe both the limited number of iterations, as well as possible points of intervention:

Teacher G: "Ok so student 2 goes back here. So, they went backwards because they were trying to figure out what it was they did, incrementally to try and improve on that"

Teacher C: "But I feel like Student 2 just got stuck at the beginning of the project, for a long time, and then they made some changes and came back, like a lot, They can back a lot by the end."

Teacher F: "Student 2 seems to have spent a good amount of time with the same concept, and then try to tinker, found that didn't work, went back to their original plan, and then tried something new, add it to that, went with a different input device completely, went back to something that they'd done earlier, and went with a pressure sensor at the end."

Student 3 was the most discussed about by all teachers, having been upgraded by most in their rankings, and standing in contrast with Student 1. The two main aspects observed were the high number of iterations and the high number of invalid iterations in comparison to all other students. All teachers look through the approaches trying to understand the type of changes the student made, commenting positively on the invalid iterations the students takes their design through to reach a valid end-product.

Teacher A: "Student 3 continues to be… that was the one I was thinking was more sophisticated anyway, and it seems like they are more willing to try things that don't function. Oh this doesn't function, this doesn't function.."

Teacher G: "the reason why they're having a high number of attempts if because they're trying a bunch of ideas that didn't work out. It's actually pretty typical of engineering ideas, it's all about open-endedness and it's ok to make mistakes. Look at their timing here, each is very very short <the frequency between attempts>"

Teacher H: "student 3 ... whilst they sat with something down here for a while that was invalid, they moved through the invalid attempts pretty quickly towards the end."

Finally, teachers' observations about student 4 also revolve around their high number of iterations:

Teacher F: "Student 3 and 4 seem to be... the students have tinkers a lot more than 1 and 2. Students 3 and 4 have put in a lot more time, have learnt a lot more about what works and doesn't work than students 1 and 2"

Teacher H: "Even though I didn't love their version as much, they did a lot of experimenting and had a lot of valid tries"

Teacher C: "It's interesting with Student 4, they go back to previous versions. I don't think this is negative, that student 4 goes back to earlier designs"

Overall, the teachers tried to keep some continuity between what they observed from the final graphs alone, into what that means for the additional information they have available from the students' approaches over time visualisation. They paired their thinking with what they interpreted as complex or simple solutions and used the added information on the design process to explain how the students might have got there. This might explain to some extent why, despite the equal number of iterations, student 3 is consistently ranked higher than student 4. In addition, the reason why student number 2 attracts the most comments around their need for intervention, from a combination of both a "simpler" solution, as well as a "simpler" journey in getting to that solution.

Blocks and Connections

Looking at the Blocks and Connections visualisation in Figure 7.3 from the four students who implemented their trap doors, the teachers commented on the variety of SAM Labs blocks the students used, the subsequent variety of resulting connections between the blocks, as well as the complexity interpreted from the number of blocks connected vertically. Rather than discussing each individual student in turn, the teachers picked up on comparisons between students and tried to build on the narrative they had observed from the first two images they had seen by that point in the interview.

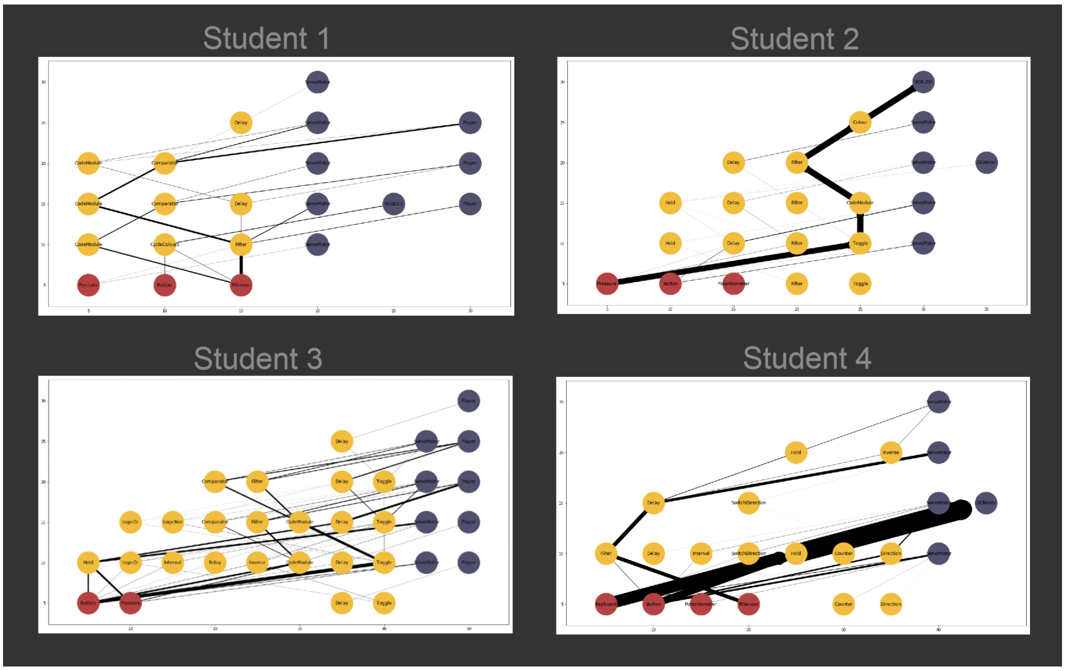


FIGURE 7.3: Teacher Evaluation Blocks and Connections

All teachers are consistent with each other in observing the contrast between student 3's high distribution across the different blocks and connections used, and student 4's convergence around three specific connections.

Teacher A: "It is really interesting to compare these two views. Clearly Student 3 was trying a lot and mixing and matching. And compared to Student 4, who had kept going back to use the same thing over and over again. Student 2, this is interesting, this line, using the same thing for a long period of time."

Teacher B: "That's a different way of looking at it, that thick line going back and forth, which means trying those things out. Here we can see clearly that there was a lot more implementation or exploration from student 3 compared with student 4."

Teacher C: "I feel like 2 and 4 are using the same circuits time and time again, instead of trying different ones. I would rather see something like 3, 1ish... 3 would be at the top of this due to the amount of connections they explore throughout this process."

Teacher D builds on the Distinct Approaches visualisation to build on in their interpretation of the students: *"So, what's interesting is .. with student 3 for example it's a LOT more connections than 1,2,4. You have a lot less lines for 1 and 2 than 3 and 4, and that is reflected in the number of design iterations they have. And then I didn't look through the design of 4 in contrast with 3, but I'm* *guessing that student 3 used a lot of blocks. Whereas student 4 went back and forth with designs but didn't use as many blocks."*

Three teachers commented directly on the complexity and variety of experimentation they observe from the visualisation:

Teacher F: "Student 1 seems to have less complexity, less experimentation than Student 3. Student 4 seems to really have relied heavily to the Keyboard connected to the Servomotor. Student 2 have kind of included some other components here, but maybe just dragging them in there and deleted them straight away. Because it seems like they have really relied heavily on the pressure the toggle, this path. Obviously in contrast to student 3."

Teacher G "This lets me take a peek of what it is that students are experimenting with in terms of the different input, outputs and connection blocks, and it tells me how many different types of logic and connects they are trying out. For example, you can see here, 2 and 4 didn't use that many connections. They have a few different pathways, but compared student 3 who are trying a lot of pathways and schematics. Student 1 is playing with the logic, but with a limited amount of connectors. This student is really trying to figure out the logic but student 3 is experimenting with a lot of different connectors because the connectors that he or she is using may not be working."

Teacher H: "Looks like student 3 really tried a lot, in a lot of different ways. Whereas it looks like student 4, they went with 1 path and they kept making that same connection a lot. And similar with student 2, they tried a few things but found something that worked and stuck with it a lot."

Whilst the teachers saw a relatively equal number of iterations between students 3 and 4 from the Distinct Approaches visualisation, the Blocks and Connections visualisation exposed the specific blocks and connections used across those iterations. The teachers stated their higher ranking of student 3, who for the teachers indicated greater usage of SAM Labs functionality and a higher willingness to experiment with different solutions.

Kept versus Discarded

From the Kept versus Discarded visualisation, all teachers converged in their observations around the ratio of kept connections versus discarded connections, as well as the timings of when the students start introducing connections they ultimately keep in their final designs.

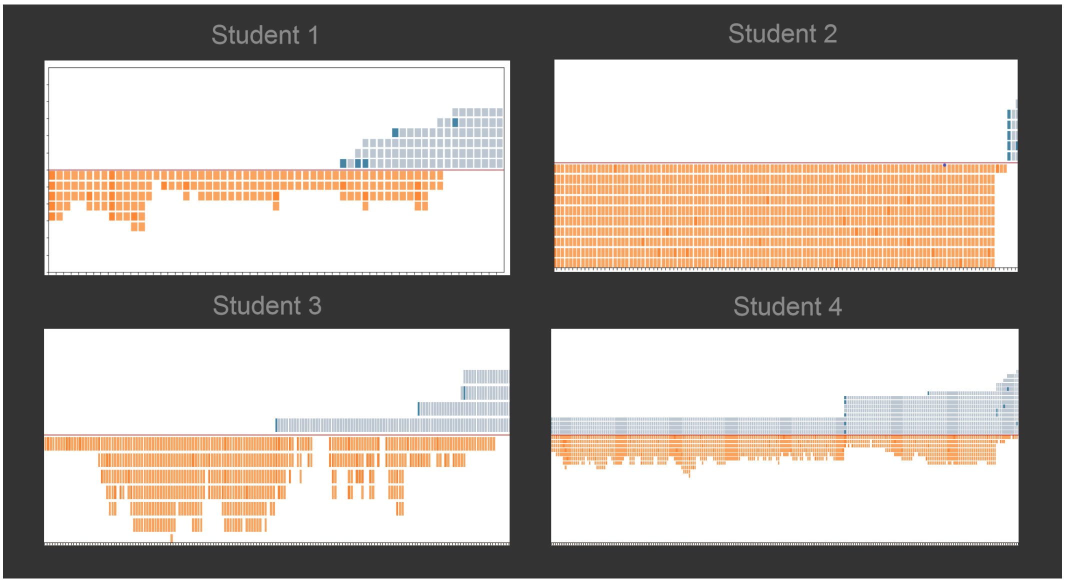


FIGURE 7.4: Teacher Evaluation Kept versus Discarded

Teacher A: "Student 1, two thirds into the process, they have certain stuff that they want to keep, and they just kept them all the time. That's so fascinating, it's really intriguing. It seems like student 1 and student 3, at least visually, it looks somewhat similar. They had ups and downs and somewhere two thirds of the way in they had stuff that, OK, I like this, this is something I want to keep, I'll keep messing with some other things, but I'll keep this. Actually, Student 4 is slightly similar too, that they try stuff out and three quarter of the way through... although number 4 had some connections they kept the whole time."

Teacher F: "It seems like they were tinkering tinkering tinkering tinker, and then they were like 'oh I got to submit the project', and then handed it in. The more segmented the graph is, the more changes it seems to show on their project. The more segmentation there is, there more it shows that they spent time making changes on the project."

Teacher H commented on the way in which the timing information complements what she had seen up until that point in the previous visualisations: *"I think this view is really good in conjunction with the other ones, from the other ones I might think 'oh this sophisticated one they just knew, they didn't try anything', this show they did try some things. It's also really interesting with student 4 that they were still discarding right until the nitty gritty at the end, and adding new blocks at the very end. But I think students 2 and maybe even student 3 the most, definitely student 3 the most it's interesting that they had a lot of trial at the beginning, but as it got close to their final solution, they were discarding fewer* *blocks."*

Teacher B identified a desirable ratio between kept and discarded they would ideally like to see for their students: *"Wow, OK, interesting. I know that we're looking at volume, but this visual looks nice because you can do a comparison, how much blue compared to orange. 1,2,3 they discard a lot of stuff, they try a lot of avenues, which didn't work, great, but student 4 seems to be.. 50 / 50. That's a 1 to 1 ratio. Let's call it implementation ratio, if it's 100% or more it's not good. You want to look at below 100%, at least, because it means you're discarding more than you're trying."*

In addition, teacher B also described what they saw in the visualisation as the time it took each student to arrive at a final solution: *"And you can notice that in terms of the volume, a lot less time it took student 1 to get to this point than any of these students <2,3,4>. So, in terms of how much time it took them to implement something, it goes 1,2,3,4. That's an easy one to see from this visual."* A similar observation is made by teacher D, who describes it in terms of efficiency: *"I think it does show, for example, that 1 and 2 had a more efficient path to the solution."*

Blocks across contexts

Finally, when the teachers were presented with the Blocks across Contexts visualisation in Figure 7.5, they were unable to comment on any additional insights gained on top of the previous visualisations. Teacher H notes: *"I'm kind of stumped by what this particular one.."*. The teachers were not able to identify anything of note from this visualisation to add to what they had already seen. Teacher A questioned whether partitioning the students' iterative design behaviour around specific blocks would be useful: *"What they technically choose to use <the specific SAM Labs blocks>, is it compelling enough as part of the larger narrative of the learning? Does it matter enough? If they choose a button over a pressure sensor? Of if they use an infrared sensor over the pressure sensor? Those might be a little bit more random. It makes me think, I could do something like 'make something that has the tilt sensor in'. But my interest would not be 'well, what did you do with the tilt sensor?', it would be more the type of experimentation that you have graphed before, what was the process once they did use it, rather than the tilt sensor itself."* Their responses confirmed that, at least in its present form, a representation of the different SAM Labs circuits the students create with specific blocks is not a visualisation that teachers identified as potentially useful. The selection of specific blocks did not aid

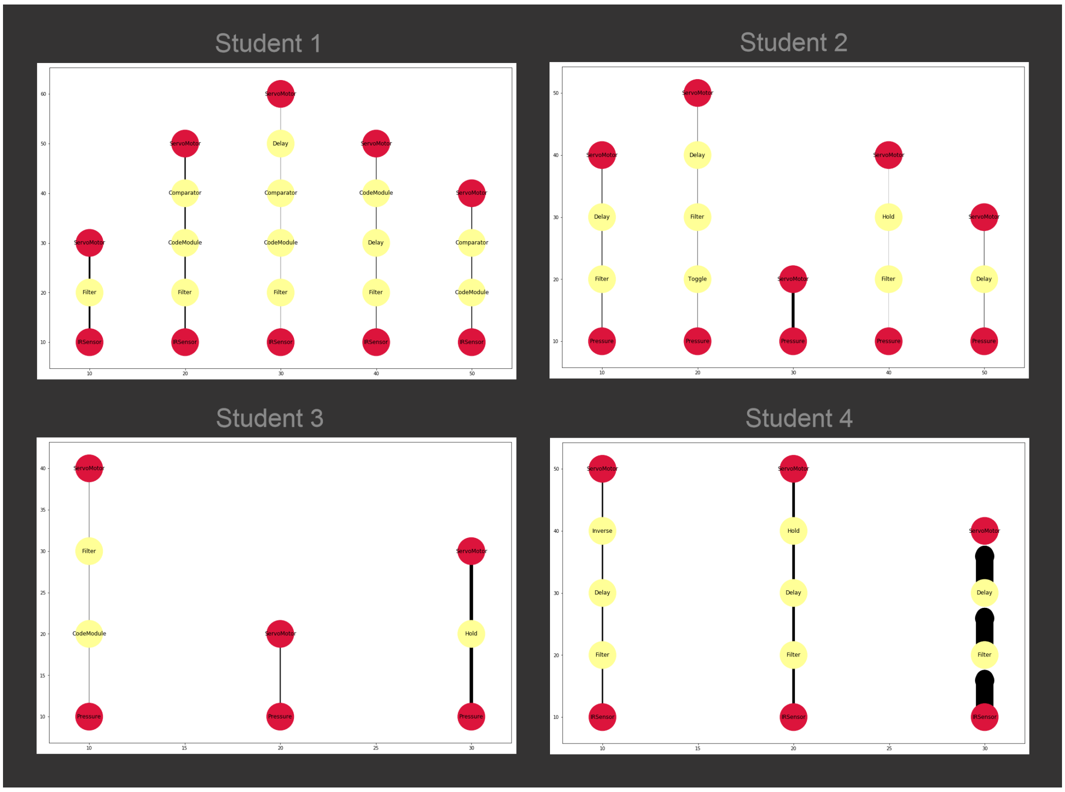


FIGURE 7.5: Teacher Evaluation Blocks across Contexts

teachers' understanding, nor envisaged support of their students' iterative behaviour.

Summary

We see from the above analysis that the teachers converged around what they saw in the visualisations, consistently commenting on the same aspects and picking up similar observations for all four students. The main aspects visible from the Distinct Approaches visualisation were the volume and variety of iterations represented by the horizontal bars, the validity of each iteration, and the complexity of iterations over time as interpreted from each design. The Blocks and Connections visualisation built on the volume, variety and complexity image the teachers were starting to put together. They consistently commented on the volume and variety of SAM Labs components which broke down the iterations visible in the Distinct Approaches visualisations, as well as the subsequent variety of resulting connections between the components. In addition, they complemented their understanding of complexity interpreted from the number of components connected vertically. Finally, the Kept versus Discarded visualisation highlighted for teachers the ratio between kept and discarded work over time. This drew attention to the volume and timings of the contributions to the final designs in contrast to the students' entire iterative design activity. The teachers were able to draw observation from the visualisations aligned with the original design goals. The observations are consistent amongst all teachers. Exploring the visibility of the data visualisations provides the foundation of the awareness and accountability aspects identified by teachers, discussed in the sections below.

7.4.2 Awareness

The awareness dimension of social translucence frames the ways in which teachers interpreted what they saw in the visualisations. The ways in which the teachers assigned meaning to the information visible to them in the visualisations is summarised below, for each visualisation in turn. The teachers discussed positive or negative aspects of iterative behaviour, differences between individual students, and possible intentions which may be motivating certain types of actions.

Distinct Approaches

The most common theme emerging from the teachers' comments when interpreting the information visible in the Distinct Approaches visualisation concerned the nature of students' engagement in the iterative design process. The teachers commented on whether they felt, from the information conveyed by the visualisation, whether the students were engaged or not, which students engaged more effectively and why, and they identified questions, generated through the visualisation, that could help them understand the students even better.

The teachers consistently associated the amount of iteration they saw in each student with them utilising the opportunities available to experiment and "test their strategies" in a positive way. Generally, all teachers related the number of iterations with the amount of work students undertook and the degree of thought they feel the students put into their designs:

Teacher G: "In my opinion, I prefer students to be like student 3. Because looking at this graph right here, I really like this curve, a lot of attempts, a lot of ideas, different ideas and different schematics but some didn't work out. Eventually they end up with the right one. I feel student 3 is the most engaged."

Teacher H: "I feel that students 1 and 3 thought more about it, thinking of different ways of making connections."

Teacher F: "This is really nice in the sense that here you can see how much work the student has actually put into their project. We struggle with that as a school a bit. We talked about introducing effort grades or something like that, alongside the grade that they receive, and the discussion always comes back to 'well, are we grading students on the degree of complication of the material at the end of the term, or are we factoring in to some egress the amount of effort already and rewarding them for that?' and my intrinsic response is, and looking at this especially, is that 'I want to reward the students that put in a lot of time and effort into something'."

At the same time, all teachers looked to qualify their interpretations using the available data, going beyond a simple "volume is good" interpretation, but looking to understand the quality of the iterations from the volume, debated what higher or lower numbers of iterations might mean for the students.

Teacher C: "Not that I think it's negative that number 1 was synthesising information and staying with the same version longer, but I feel like number 3 was thriving in the process. Especially in this part of the project <where the invalid versions are>, I feel like 3 really was thriving along the way."

Teacher E: "Positively, you can see that kids are utilising the opportunities to test their strategies, so they're obviously engaged. 3 is working it, he's really trying. This is cool how you aggregated this, it is impressive". Teacher B: "You can see each time they are doing something different. Looking from the beginning, in terms of the logic, it's gradually improving so you can definitely see growth. They're playing around with the logic, not just plugging in different things to try out different ideas but trying to hone in their idea with the logic using the same components. I feel student 3 has shown the most growth looking at this data."

Teacher B: "You can see a nice progression here for student 2, even if it was a simple one. Clearly for this student it was difficult to put things together, and I guess maybe that can be seen when he goes back to the versions here. In terms of progression, I like this view."

Another way in which four teachers qualified the movement through iterations was based on the students sometimes reverting to previous versions.

Teacher A: "Student 2 goes back to what he's previously tried, this is good, you know, this didn't work so let's me go back to previous implementation that did.

This is good"

Teacher D: "I want to teach kids to move beyond trial and error. You don't want students to just try things out until they work, but get to the point of 'the proximity sensor is better than the pressure pad for this reason'. It seems like what they are doing is saying 'this combination of things works better than all the other combination of things that I've tried before'."

Teacher F: "they laid on a solution that didn't include the code block. What that tells me is that they realised they could use this particular tool, but they chose not to because it wasn't necessary to accomplish what they were trying to."

Whilst the teachers discussed how they interpret the information in the Distinct Approaches visualisation, it also prompted them with specific questions they might ask students or themselves, should the visualisation represent their classroom. The questions were linked to either the project design or around the student's intentions.

Teacher A: "it definitely opens up a lot of questions for me, about the students, and the process... that's really exciting to me. I really love how you can start asking questions, the data is over time, so were there key moments promoting the students to rethink their work? "Like student 2, I wonder what happened at this juncture <after the first valid version>?"

Teacher H: "Maybe this is where it would be great to talk to the student and say 'what were you thinking at that point in time?'"

Teacher D: "But if they are going back and forth between the same device, then why are they making that decision to go back and forth?"

Blocks and Connections

The Blocks and Connections visualisation prompted teachers to further explore students' iterative design behaviour around effort and exploration. The teachers built on the narrative from the previous visualisation about the four students by commenting on the components and subsequent connections they had used, further cementing their interpretation of the students' progression:

Teacher G: "So this is what it's telling me: how much efforts are they putting in, in trying new things, explore new parts, new inputs, outputs, and coding logic."

Teacher D: "This is a really interesting data visualisation, I've never seen anything like this before. Based on this, you can see, students 2 and 4, they have a base, which they are comfortable with. Every time they don't succeed, they go back to that base, that schematic. And student 3, they try different things, go back, and try other things. This is a really dynamic student."

Teacher H: "I love that student 3 were ready to try something different. Even though they found things that functioned, they wanted to see what else they could do with it. I think that can be really great. But I think student 1, the more I see it, this was the kid that found a way to do it, and was done. Which I think is... even if their final graph seemed really sophisticated, it maybe could have been even more sophisticated if they had done more experimenting."

In addition to the students' iterations, Teacher D also considered the visualisation telling around the efficiency with which the students arrived at their final solution: *"So it seems like this is another way of seeing the efficiency of their design process. Maybe student 2 had the most efficient design process, maybe? A thick line for one circuit, less outputs, so I'd have to dig into it a bit more, but maybe this is a way to demonstrate the efficiency of their design process."* Teacher E used the Blocks and Connections visualisation to compare all students in terms of their efficiency: *"Student 1 is efficient. Student 3 is creative, very creative. They are wanting to test, they are finding things that don't work, and when they get to the system that they like best, they are sticking with it and testing it multiple times. Student 2 found the right way, and kept doing it. They tested a little bit, but once they found what they wanted, they stuck with it."*

However, what two teachers associated with efficiency, three teachers associated with a potential problem: *Teacher B: "Yeah, well look at it again. If we look back at what I said <when talking about the previous visualisation>, student 4 looks like they were kind of stuck, and didn't explore other things."*

Teacher F: "I feel like student 4 kind of got in a rut, thinking, 'this is the way I've got to do it', whereas student 2 played a little bit more, but mostly did the same thing."

Teacher H: "Student 4 only knows how to do it one way. The tried a couple of times, but it was too hard, and went back to their other way."

Kept versus Discarded

From the Kept versus Discarded visualisation, all teachers continue to build on their previous understanding of the students' iterative behaviour from the other two visualisations, focusing on analysing what the students discard, rather than what they keep in their final solution. The discarded work emphasises the different amounts of effort the students put in even for students whose designs are similar:

Teacher A: "That person, I keep coming back to Student 3, maybe this marker of this person who has a lot of resilience. If you spend that many iterations with failed failed failed, there's a level of curiosity and resilience that's interesting."

Teacher C: "The other thing that it makes me question. On an external level, for me as a teacher it would be like 'oh, they're not really doing something super creative. They're just taking my chopping mechanism idea'. But this <the visualisations> seems to suggest that even when you're giving them an idea to go down, and it's an open-ended situation, they're still going to be using that creative, problem-solving, trial-and-error. It's not like they just copied everybody and they're doing the same thing, so they're not really learning."

Teacher B and D also tried to quantify the ratio they would like to see for their students:

Teacher B: "Let's call it implementation ratio, if it's 100% or more it's not good. You want to look at below 100%, at least. Cause it means you're discarding more than you're trying. It could be that you latch on to something really quickly and you get it. It could be by chance you end up being lucky you end up with exactly what you want. Student 2 has the smallest implementation percentage but they keep very little. Student 3 too. But student 4 seemed to go back and forth."

Teacher F: "Obviously I like more changes, more experimentation. The more highlighted blocks, deep orange or deep blue which means they've tried components that they haven't tried before."

Three teachers commented on the timing aspect of when students start building towards the final designs, and coordinated the discarding ratio with the project timings:

Teacher G: "I think, for me, what you want is something like student 3, where blue meets orange roughly at the half-way mark. The y axis doesn't need to be high, but I feel like that gradually they are ditching the old and bringing something new because they are experimenting, figuring out what's right and wrong, and then, at the end, there it is. And then for student 2, they're not really exploring. At the end they might have got an idea maybe from another student and 'here's my final product'"

Teacher H: "3 they were really making a plan and finding what worked with it and keeping it, as opposed to just trying out everything"

Teacher A: "Two thirds of the way through there is this jump up for student 3. That makes me wonder.. Is there a deadline there, a lesson there, what was it that happened in the classroom at that point in time to spur on some of that finalisation? That's really interesting, at some point, clearly something happened that day that cause that student to finalise their designs."

Summary

The awareness aspects presented in this section respond to the design goal of the data visualisations to expose dimensions teachers value around students' iterative design process, as outlined in Section 4.2.3. These are confined to the information the visualisations make visible. The aspects teachers identify revolve around engagement, efficiency and growth. The teachers discuss the quality of engagement in terms of effort, variety of ideas, complexity of attempts, volume of iterations and degree of discarded connections. They discuss efficiency in terms of speed, simplicity and synthesis of ideas. Finally, they discuss growth in terms of progression between iterations, logic applied to changes between sequential versions, and having a systematic approach to their testing framed within an objective. These aspects include and expand on the three dimensions of variety, validity and complexity presented in Chapter 6, showcasing the nuanced ways in which different teachers interpret the same information. In addition, they offer potential ways of framing and expanding on the three dimensions in future research.

Tensions appear at times between what teachers consider either positive or negative signs in the aspects presented above, when discussing the individual students: whilst some teachers considered student 1 "efficient", others considered them "simple" or "unchallenged". Likewise, whilst some teachers praised student 4's overall high level of activity, other teachers deemed the same activity as "pure hacking with no plan or objective". These are aligned with the tensions identified from the data analysis in Chapter 6, showcasing the dependency on knowing the students' aims when constructing, in order to make a judgement on whether an emerging dimension might be indicative of an either positive or negative characteristic of students' iterative activity. Furthermore, despite the differences in what the different aspects might mean for each individual student, the teachers converged around their relevance to the design and support of students' iterative design behaviour. In addition, all teachers qualified their conclusions within the constraints of the evaluation setup – in any real-world scenario, they would know the students, had participated in the classroom themselves and would confirm their suppositions by corroborating their understanding with the students themselves. They highlighted the limitations of what data visualisations can provide them without any knowledge of the wider context or access to the students' own voices. In addition, a common underlying qualifier emerged which drove the characterisation of each aspect in the case of each student: Do the students make informed decisions based on evidence as they go from one iteration to another, in the context of their intentions as project objectives? The role of the visualisations in helping students and teachers improve their iterative design behaviours further is presented in the next section.

7.4.3 Accountability

The accountability dimension of the social translucence framework refers to the norms, rules or behaviour changes the teachers perceive the visualisations might lead to in the classroom. This is explored in the fourth part of the interview. The accountability factor is presented in terms of the different potential teachers identify for the use of the visualisations in the classroom. Five themes emerge from teachers' answers in relation to accountability:

- Continuation of current documentation and reflection processes
- Generate informed and specific questions
- Tracking the impact of project design and teaching interventions
- Sharing the data with students for self-awareness
- Use the data for evaluation purposes

These are expanded in their own sections below.

Continuation of current documentation and reflection processes

The main use identified by all teachers for the visualisations revolves around complementing current documentation efforts towards a more comprehensive view of students' actions and improved guided reflection. The view of the students' activity as it emerges from the visualisations provides a continuation of what teachers observe in the classroom, and existing documentation practices the teachers already get students to report on. Illustrative quotes are:

Teacher B: "I think this is just one of those things, the type of project where there's not a lot of commenting going on, even taking notes I find that is difficult. Here we're seeing the thought processes."

Teacher F: "This would complement a type of diary, or journal. My colleagues and I are still struggling to do that. Not just in programming, but in the design class in general. Trying to get students to reflect back on what they tried, because that's the key to getting them to understand where they went wrong and what not, especially if it's part of their learning process."

Teacher D: "I think they provide a lot of useful information. Very helpful. It's another way of documenting the process along the way. My students, when they engage in their design process I gather a lot of data on my students' thinking. I do a lot with my students' self-reporting, and I have things where the students are showing the things along the way they are changing and showing their thinking, but I do not have a program that shows the changes and revisions. It makes it more accessible and easy to view and to look at. And I think it yields a more complex understanding of the process that the students work through and the challenges, if you use this in addition to what you already do in the classroom."

Specifically, five teachers valued what they perceived the visualisations to be a "window into the thinking of the students", as a representation of their actions. The five teachers valued the direct connection between the information in the visualisations and the students' activity in the classroom, and the value of tracking a version history of students' actions to complement the end-product.

Teacher D: "I think I would use it because I think this shows a window into the thinking of students. About their process and design. I think it gives teachers more information than just the product the student is creating. It's more information to the teacher than just like transcripts of their experiences and what they're thinking, or what they're documenting. It provides a continuum of their process, to really see their thinking along the way. Especially if you were to cross-analyse this with the things that students were self-reporting."

Teacher G: "I think it's great. We have Google Docs, and it's a great way to document what they are doing when they are doing it, because it has version history.

This is the SAM Labs version of Google Docs, where I can go in and look at it. I definitely think they would appreciate the schematics, the screenshot of the schematics as they are progressing. So maybe like every time they are working on it or every day, it takes a screenshot you can kind of see their progression. Yeah, I think that would be super fantastic, if you had something like this. Not just for student, but also or teachers, with their progress and what their thinking process is."

Teacher H: "I really like, especially this view (the Distinct Approaches visualisation), because typically in a class of 30, I only get to see the end-product. I don't get to see the pieces leading up to it. I especially have some really nervous and shy kids. If they think they've done something wrong, they don't want you to see it."

Generate informed and specific questions

The other way in which seven teachers explained how they would use the information provided in the data visualisations was by identifying specific questions to better understand the students' activity and support their goals. Having a record of the students' actions from which to draw concrete examples to discuss further was identified as a valuable tool for the teachers' practices. The teachers separated between the different roles information presentation can take, positioning the visualisations as "question generators".

Teacher B: "There are a lot of things that will fall through the gaps. That conversation piece is always going to be necessary. And documentation is even better. We need to find a way for them to document chronologically but also in an easier format."

Teacher F: "I would definitely use it to target the type of questions and discussions you have with the kids. It creates really good opportunities for discussions with students."

Teacher H: "So I would be interested to ask this student what they liked and didn't like about these first two. And why they decided to change. Which I think adds a nice language piece when you're assessing kids 'why did you make that choice?!'"

Teacher E: "So the questions that you ask during that process, as a teacher, is where you do your work. The visuals would definitely prompt me to ask more specific questions."

Furthermore, four teachers envisaged concrete ways of using the visualisations with students as part of their documentation and reflection process, getting students to explain their decisions during the construction process:

Teacher D: "So I've never seen this kind of approach in any kind of comparable tool. Whether it's LEGO Minstorms or Arduino controller, and I think it's fantastic. So how I would use it, underneath this visualiser I would make them give an explanation. Like you comment code to explain to other people and to yourself, why you're doing this thing. Good programmers will save their multiple instances as they are going, and say, this is why I did this thing before, and now I'm doing this thing for this reason. I want that history so I can see what the evolution of this is. This allows you to do the evolution of not just your code, also your circuit. So, I would put in here the ability for students to comment on why they've done this and the reason why they've changed it, and why."

Teacher B: "I'd get them to also write some data in there about how this performs. And you can look to see how the other thing performed, and you can compare them and make decisions as they are going based on that data. I think that would be great, it's a super cool tool. In the end, if this comes back to the teacher, the teacher has a history of design decisions. Based on data, and that's wonderful. You can use this as your entire criteria for evaluation of how the students built their circuits. Did you make design decisions based on evidence?"

Teacher F: "When you're in a classroom and working with students you often don't see those iterations that they go through. And I think you gain a tremendous amount from knowing the history of changes. Absolutely. You can start to understand their thinking process. I think it is aided a lot by having them explain those decision, like in the first visualisations if they were able to put text to those changes, and I've certainly done that where I have students explain and I have students write out when they're going through changes and why, but typically in coding challenges, or circuit challenges, you don't do that, considering that they happen so rapidly. So, I think it's extremely valuable to have that history of changes."

Tracking the impact of project design and teaching interventions

Another use four teachers identified for the visualisations was tracking the impact of specific interventions or lessons across the variety of pathways students take in open-ended settings, across different projects and contexts, and comparing the nature of students' activity across the different stages of the design process. Example quotes are:

Teacher A: "This is really cool. I can imagine having a second layer showing the lesson context, so that you can say 'here's the lesson for that day, which generated this particular section of student activity'. One of the main things about these open-ended projects is that students go in all sorts of directions. I think in process and experimentation in an open-ended environment… the connection between what is happening specifically in any given day, and the new activity that is coming in would be really helpful. So could I bring in some kind of new information, and see what happens. So, I know on this particular day I brought in this new idea, but nobody took it. Or many people took it and it was potentially can be a game-changer in the type of lesson I present and the kind of information I presented."

Teacher B: "It could mean that, in the ideation portion of the design process, you're still at the development stage. That could show up, like it did for student number 4 for example. If you nurture the students in an environment where we're all about the learning and the process, these types of tools really work."

Teacher H: "I think for me as a teacher, if you had more than one of these projects, to look at how the kids change throughout the year, and see if they are continuing to try new things, or do they get 'I've learnt now, I'll just do it', which is maybe not as much what I would want from them. I would want more of the experimenting and the trying, to see what would happen over time."

Three teacher commented on using the visualisations to enhance their diagnosis of where their help is most needed and to diagnose specific incidents:

Teacher F: "For a teacher to get that, to be able to understand what students are thinking as they're going through, I think it affects what you do in the future, it affects what you do on a day to day basis. If you see them going back and forth between these two sensors for example, then that means they don't really understand how to test out a sensor. So maybe I'm going to introduce a lesson where we're going to collect some evidence about which sensor works better for their application for example."

Teacher E: "Where I would look at this is for a student who is struggling. For them I would dig in, with as much data as I can, what they've been doing. And then I would look at this and say, for instance, if they are in student 3's category 'I see you've spent a lot of time on a lot of different things. Let's back up: What does a sensor do, and what does a filter do?' This makes me think back of the concept of scaffolding, and how that applies to project-based learning. In the traditional classroom, we talk a lot about scaffolding and being able to help students develop more complex projects. The temptation with open-ended projects is to throw that *scaffolding out the window and just tell students: 'here are the concepts and tools we're working with here, go crazy.' But scaffolding still plays a role in that, you still have to provide a certain structure."*

Teacher H: "I think this view would be really interesting. I had two of my students who chose to use micro:bits first, and they played around for a little bit, we talked about how this was something we had less experience with and that I could help, but that we hadn't done it a lot. But they gave up pretty quickly. And it would have been interesting to see what connections they were making, and what connections they were missing, before they switched into something else."

Sharing the data with students for self-awareness

A fourth category of observations from teachers pertaining to the accountability of the data visualisations concerned the sharing of the data with students for their own use and awareness. Two teacher commented on sharing the data with the students and using it as a self-reflection tool for the whole classroom:

Teacher A: "I think it would be great as a tool for kids to go back and use it as their own visual. Being able to have students generate assessment of their own work I think would be really exciting. Kids hate that kind of work, but I think when they can look at their own story, and they can generate a story that they can tell about their own actions, I think that can be really powerful. So, it makes me wonder about taking this data and then letting the kids think about it also. What if kids saw it and talked about their own data?"

Teacher H: "I'm a big fan of sharing data with the students. So I think showing the kids this view, and saying 'what do you guys think is going on here', I think they would have the same kind if insights like 'oh, that person didn't try as many things, but that person tried a LOT of things.' and then talking about the pros and cons of that."

Use the data for evaluation purposes

Four teachers also discussed the ways in which the data visualisation could form part of their evaluation and assessment in project-based open-ended settings. They connected what was being done at their school in terms of assessment and the methodology used in designing the visualisations:

Teacher A: "I shared our conversation and some of the work you've been doing with my supervisor who is the Director of Technology at the school. I feel like the *work you're doing has implications for a larger work that she wants to be doing specifically around assessment, and looking at the process of learning. The tool you are using and the methodology you are using in your study is compelling."*

Teacher E: "Being able to know what a students' effort really is, it allows the teacher to say 'hey, I see that you worked really hard at this, but I can also see that something is not clicking. First of all, it's not you, it's not your problem, this is our problem, and I want to make sure we're able to figure out how to help this, how to make this click'. That is a lot more ultimately successful in the classroom."

Teacher D: "You can use this as your entire criteria for evaluation of how the students built their circuits. Did you make design decisions based on evidence?"

7.5 Discussion

In this section, the results are summarised and their implications for the design of data visualisations are discussed.

7.5.1 Data visualisations to describe the students' iterative design process

In the evaluation, the teachers identified preferences towards students' level and nature of iterations. The teachers unanimously considered the amount of experimentation leading to the final design a worthy aspect to consider and reward students for. They felt that the higher number of approaches explored by the student were positive signs, exposing them to a variety of components and behaviours. They also generally saw the invalid approaches as positive signs of confidence in terms of the student both being willing to try things that do not work, as well as persevering to reach a valid end-product. They associated volume with a willingness to make mistakes, to explore, to test new strategies they might be unsure of, to learn about what works as well as what does not work, to persevere through multiple iterations, have the curiosity to test different approaches, think of diverse ways of making connections and achieving their goals, or the amount of thought and effort that went into their project and growth.

All teachers highlighted that simply a large volume of experimentation does not necessarily lead to positive outcomes, and indeed can be a sign of being stuck with the same problems. They looked further for signs of quality in the students' amount of iterations, such as the complexity of iterations over time, the logic between iterations, timings of reverting to previous iterations or proportions of discarded iterations. For the students who showed lower volumes of iterations, the teachers conjectured efficiency, especially in the case of student 1 who produced a computationally complex design. However, they also down-ranked the student against their peers who iterated more, wondering whether the student is more right-answer focused, reluctant to make mistakes, aiming to get it done as soon as possible using what they already know and not reaching outside their comfort zone.

The visualisations were able to expose specific aspects that teachers look for in understanding their students' iterative design behaviours and qualifying these based on the information available to reach preliminary conclusions about the students.

7.5.2 Focusing on the process and implications for data visualisations

From a pedagogical perspective, teachers repeatedly highlighted the importance of the procedural aspects in getting students' to engage with "hard content" in open-ended projects using physical computing kits. When describing their SAM Labs teaching experiences, the teachers not only expressed the value of the iterative design process as a stand-alone, concrete learning objective in itself, but positioned it as a means towards also acquiring academic knowledge and understanding of computational or interdisciplinary concepts. During the ranking of students' approaches, there was a clear difference between the criteria teachers applied to judge the students' end-products, and the criteria used to re-rank based on added iterations data. To interpret the designs, the teachers focused on the complexity of the SAM Labs designs, whilst looking at the students' iterations prompted teachers to change their evaluation priorities, and therefore their subsequent interpretation of the students' learning. Finally, the visualisations evaluation exposed the recurring question teachers turned to as an underlying guide used to interpret the students' iterative design behaviour: "Do the students make informed decisions based on evidence as they go from one iteration to another, towards achieving their project objectives?".

From a data analysis perspective, focusing on academic knowledge acquisition or end-products to interpret the students' activity can yield inaccurate representations of what might constitute positive or negative behaviours.

Conversely, focusing on describing the students' activity from a procedural perspective can lead to an easier identification of the behavioural causes which might or might not lead to improved learning outcomes. Designing process-oriented tools for teachers also has implications for inclusion. Teachers repeatedly highlighted the challenges in getting students to consistently document their iterations, especially when dealing with nervous or risk-averse students who are unlikely to showcase work-in-progress. The teachers also emphasised the link between process and growth mindset (Dweck, 2016), highlighting the value of recognising effort and thinking process above a final product for students' own understanding of their capabilities to learn and progress.

The consequence of focusing on the iterative design process as a learning objective, as well as the subject of the data analysis, leads to it being concretely acknowledged as part of the learning mechanism, made visible and traceable. Teachers often referred to practical design interventions that they implement to encourage an iterative design process, such as documenting changes, acknowledging effort, encouraging mistakes, or showing evidence of the experimentation which led to their end-product. This in turn makes the iterative design process be intentionally considered and practically designed for and integrated within the projects. These intentions are followed through in the design of the data visualisations, providing a continuation of current practices teachers are already employing in their classrooms.

The focus on procedural behaviours also acknowledges a certain hierarchy of priorities during learning, with the effort, the attempts, the volume of iterations constituting the basic foundation on which more sophisticated heuristics are derived from: effective effort, productive mistakes, systematic iterative design. Focusing on higher level derivatives whilst ignoring the basic activity upon which these are built risks de-valuing and distracting from the necessary detailed layer of activity which students build on to reach systematic, productive, effective behaviours. Data visualisations can be used to delve deeper into the detailed layer of activity, and making it more transparent, therefore open to critique and improvement.

Finally, trying to represent the process exposes tensions and contradictions between learning objectives: *"on one hand you want to see students solve a problem most efficiently, but then you also want them to show evidence of skills and competency and computational concepts"* (teacher I). Tensions between efficacy and exploration, between complexity and effectiveness, between simplicity and variety, appeared in the teachers' commentary. This unveils complex ideas that sit in balance not only in pedagogical research but also in teachers' perceptions, difficult to converge around a single interpretation solely from the data. Grounding data visualisations in activity descriptors such as variety, validity and complexity can help expose these multiple ways of interpreting students' behaviours, leading to more diverse and comprehensive ways of judging students' performance, against equally valid objectives.

7.5.3 Data visualisations as extension of current understanding and practices

The data visualisations stand as extensions into the awareness teachers already have of their students and their activity. By focusing on various ways of representing how students iterate through versions of their SAM Labs design, the data visualisations attempt to make visible the students' activity in a way that teachers can analyse for themselves. Repeatedly, the teachers noticed the enhanced contextual understanding that the visualisations offered as a *"history of design iterations based on data", emphasising the complementing role the visualisations played for them: "When you're in a classroom and working with students you often don't see those iterations that they go through"* (teacher D). Teacher A interpreted what they saw in the visualisations through the lens of their own students: *"I think it pretty well matches the types of different learners that I have. When I saw the data and thought more, I started seeing certain types of students. I can find those 4 students in my class for sure."*

Designing data visualisations in a way that builds on the information teachers already have from their classrooms, rather than trying to entirely reproduce it, enhances rather than replaces teachers' richness of expertise and intuition. This also allows data visualisations designers to focus on specific enhancements, without aiming to provide a comprehensive view of all possible dimensions and perspectives at play in complex learning contexts. In addition, it leaves the teacher in charge of collating various factors to make decisions, rather than using single data analytics perspectives. This is explicitly articulated by Teacher A: *"I know a lot of education software is about tracking and figuring out where things are going. But I think that idea of being able to connect the visual piece and actually see what they did and how they did is so valuable in the long term."*

The goal of expanding awareness without decisive interpretation cuts across all aspects of accountability identified in the results section above. The potential for the visualisations to be used as enhancements to the current documentation and reflection processes, of generating informed and specific questions to aid teachers' understanding and students' self-awareness, of tracking the impact of project design decisions in light of resulting student activity, or sharing the data with students and even using the visualisation for assessment purposes, are all positioned as continuations of existing understanding and practices.

Finally, we comment on the awareness role of the data visualisations in the context of their potential for behaviour change for students. This was highlighted in the potential teachers identified in sharing the data with their students for students' own self-awareness. The data visualisations were positioned as concrete, tangible depictions of the iterative design process, which can otherwise be an abstract construct for teachers to present to students. Teachers were excited at the prospect of sharing these with both their colleagues and their students at the beginning of the project, as a way to exemplifying what the iterative design process entailed such as frequent testing, perseverance through errors and exploration of a variety of ideas. Two of the teachers used the visualisations post-interview, in their current format, from the four students building their trap doors, to discuss with their own students the trial-and-error process, its non-linear and multi-dimensional nature, and provide examples of getting students to document the changes they make throughout the project. Whilst the responses were not tracked, it does lead to further questioning around the effective ways in which visualisations might be used, differentiating between pre-emptive awareness and preparation to guide future behaviours, versus real-time or retrospective interventions.

7.5.4 Data visualisations as "question generators" to better understand student intentions

As well as a continuation of current classroom practices and contextual awareness, the data visualisations also stand as extensions into students' thinking and intentions. The visualisations were often interpreted by teachers as "question generators", to either verify their own understanding of the students' thinking, or to corroborate with their construction goals. Whilst the teachers provided a possible narrative, hypothesising on whether student 1 was being efficient or taking shortcuts, student 2 was struggling or being effective, student 3 was inventive or undecisive, or student 4 being exploratory or lost, all teachers converged around the dependency of those decisions on what exactly the students were trying to achieve: *"This whole process is just brilliant.. you can tell the story, and I think the story itself is what becomes so valuable. This data really tells the story, and we need to fill in the human side. I can make all sorts of guess, but please, tell me about these kids."* (teacher A). They articulate both what the visualisations do, as well as what they don't, which is exposing the "human side", the students' voices. For teachers to be able to decide whether the students make informed decisions based on evidence towards achieving their project objectives, the students' intentions, the project objectives they construct need to be exposed to complement the data.

Chapter 8

Conclusion, Limitations and Future Work

This chapter summarises the thesis's main findings and contributions towards the design and evaluation of data visualisations which aim to expose primary school students' iterative design behaviours when using physical computing kits in open-ended learning contexts. Design implications for using trace data to characterise aspects of the learning process independent of end-product are presented. The chapter concludes by outlining the challenges the present research posed, recognising its limitations, and identifying directions for future research.

8.1 Summary of contributions

This thesis advances the study of students' learning experiences when using physical computing kits through data visualisations. To that end, the iterative design process was identified as a core learning objective integral to students' engagement in design tasks using physical computing kits. Open-ended design tasks were recognised as the most appropriate contexts in which to study the iterative design process. The concept of appropriation was emphasised as the theoretical lens at play in such contexts. Finally, we explored to what extent and in what capacity certain data visualisations prototypes might support students' learning in such contexts. Overall, the present research has contributed to furthering understanding of the iterative design process students engage in during open-ended construction tasks and the role data visualisations can play in supporting their iterative behaviours.

Figure 8.1 summarises the ways in which the thesis's contributions emerged from answering the research questions, as an extension of Figure 1.1.

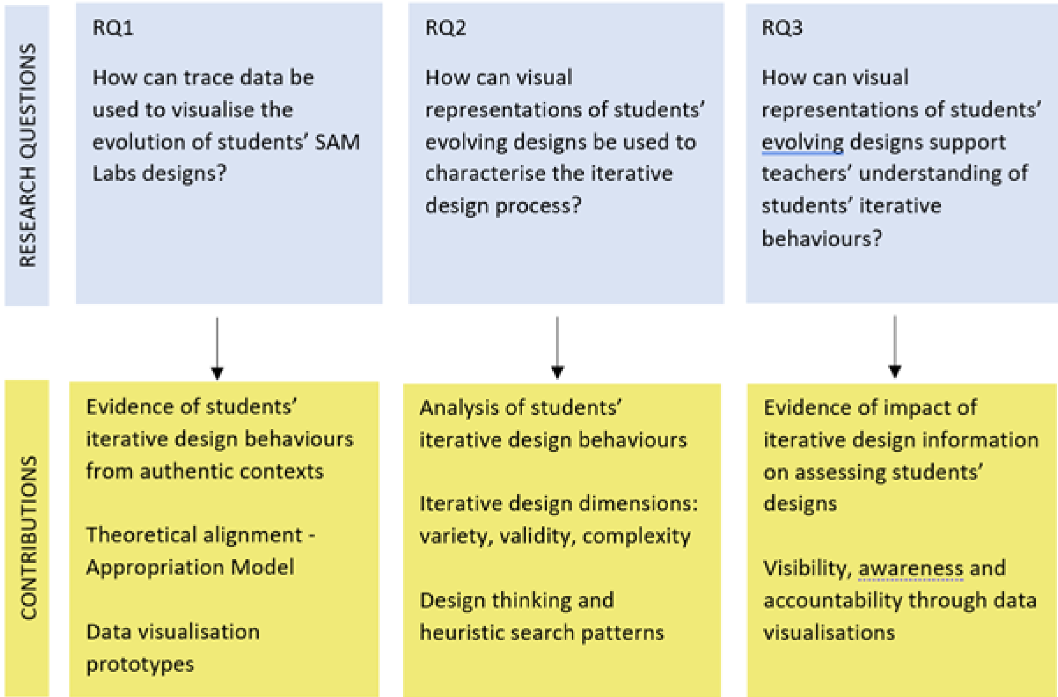


FIGURE 8.1: Summary of research contributions

8.1.1 Contributions of the first research phase

1. How can trace data be used to visualise the evolution of students' SAM Labs designs?

The contributions of the first research phase are presented through outputs from investigating the first research question, consisting of three steps taken to arrive at visual proxies aimed at characterising students' iterative design.

First, the educational 'challenge' of enabling and supporting students to practice the iterative design learning objective was studied in authentic learning contexts. Qualitative observations informed the definition of the educational problem as: *SAM Labs designs evolve in relation to functionality goals through a series of iterations students often find difficult to document or articulate, leaving teachers with little information to assess the process students engaged in to arrive at a final design*. Examination of the students' iterative behaviours exposed the idiosyncratic ways in which students interpreted the construction challenges, leading to a high degree of variability in students' designs, in line with their personal goals. Furthermore, the students appeared to be motivated by achieving their own target behaviours, refining their goals in line with the design evolution. Challenges were observed in students articulation of their thought processes as they progress through iterations and justifying the evolution of their designs. Students were found to be reluctant to share their less successful steps or document their work in progress. On the other hand, teachers looked for ways of integrating the process students take to arrive at their final artefacts into their assessment and support strategies.

Second, a theoretical model was created that contextualised the practical manifestation of students' iterative activity in appropriation theory: *an Iterative Design Appropriation Model*. The model builds on the affordances of open-ended design tasks using physical computing kits to align the evolution of student construction goals in line with the SAM Labs kit's functionality, as it emerges from design iterations. In the context of SAM Labs design projects, appropriation is interpreted as the optimisation process of the students' self-identified goals in relation to their iterative design activities, which are continuously adapted in relation to each other. The appropriation model was used to shape the formulation of *data visualisation goals* and interpretation of the data analysis.

Third, a set of *data visualisation prototypes* were designed as visual proxies to characterise aspects of students' iterative design behaviours using trace data. The changes between design versions captured in the trace data are described in relation to the iterative design learning objective as integrated into the board game project by the teacher. Using the changes between versions as the unit of analysis, questions are formulated that align with the iterative design activities incorporated into the project. A quantitative ethnography methodology (Shaffer, 2017) was used to describe the changes between versions over time, offering a process-oriented terminology to describe the trace data across time. A line, conversation and stanza quantitative ethnography model was generated, with the trace data segmented into parts that are representative of SAM Labs constructions' evolution over time. Finally, a set of visual prototypes intended to map the data available in the trace logs to the ways in which student evolve their SAM Labs designs over time were presented. Inquiry points pertinent to the students' iterative activity were identified as incorporated into the visualisation prototypes, and later evaluated with teachers.

8.1.2 Contributions of the second research phase

2. How can visual representations of students' evolving designs be used to characterise the iterative design process?

The second research question was investigated by exploring students' iterative design behaviours through the data visualisations, resulting in three main contributions.

First, seven students' iterative journeys were investigated. Video, audio and digital journal records were used to complement the information emerging from the data visualisations, to produce an analysis of students' iterative design behaviours, aligned with the appropriation model, of the ways in which the students' SAM Labs designs are adapted along with their functionality goals.

Second, the students' iterative design activity, as it emerges from the data visualisations, was described through three dimensions: *variety, validity and complexity*. Each dimension was defined in the context of students' evolution of their SAM Labs designs and aligned with pedagogical implications. The relevance of each dimension was investigated in the context of students' work, and further probed during the evaluation with teachers.

Third, two *design thinking and heuristic search patterns* were explored through the data visualisations from the analysis across all students involved in the research:

1. The pattern of convergent or divergent search of solutions across SAM Labs components to achieve specific behaviours. Some students converge around a few specific components to refine the functionality in detail, whilst others diverge across a larger number of components, looking for a solution from a greater variety of designs. The pattern does not apply to students, but to the specific construction project students engage in. The same student can take a convergent approach for some constructions and a divergent approach for others, highlighting the role students' goals have on their iterative design activity.

2. The volume and timings of discarded work are consistent for most students in the analysis cohort. The students discard more connections than they keep, and they start building toward their final solution in the last third part of their available project time, using the first two thirds mostly for experiments that they mostly discard. This pattern

emerges consistently for the majority of the students, in two thirds of the projects analysed in the research cohort, with students appearing to separate between the time they have available to experiment and try out alternatives which they do not intend to keep, and the time during which they build towards their end-product, where a lot less work gets discarded.

Finally, the data visualisation analysis exposed pedagogical tensions that arise from students learning in open-ended design projects using physical computing kits. The tensions revolve around the validity, variety and complexity dimensions and what they might indicate about the students showing high or low levels of each dimension from a pedagogical perspective.

8.1.3 Contributions of the third research phase

3. How can visual representations of students' evolving designs support teachers' understanding of students' iterative behaviours?

The contribution of the third research phase consisted of the evaluation of the data visualisations with teachers. For the evaluation interviews, the data visualisations were used as "objects to think with", intended to prompt teachers to comment on specific aspects of students' iterative activity. The teachers' answers to the interview questions were analysed using the social translucence framework, focussing on the *visibility, awareness and accountability* the data visualisations convey.

The analysis showed a clear distinction between the way in which teachers assessed SAM Labs designs purely based on end-products, in comparison to seeing also some information on the iterative process students engaged in to arrive at the final designs. All teachers welcomed the additional information the data visualisation prototypes attempt to convey, and the majority (80%) changed the order in which they ranked the students in light of the 'Distinct Approaches' visualisation. The teachers were found to value and account for the way in which students engage in the design process, in addition to what they produce as a final design.

In terms of *visibility*, the teachers consistently associated what they saw in all four visualisations with "trial and error", "changes", "workings" and "experimentation", in alignment with our primary goal of the visualisations to convey aspects of the students' evolving designs. In addition, the teachers repeatedly commented on the value of having visibility of the students' work in progress, as a means of further probing students' decision-making process as they work through iterations. This is in alignment with our goal of positioning the visualisations as a reflection tool, as "questions generators" to help teachers better enquire into the aspects of students' work that are not visible from just the trace data.

Relating to *awareness*, the visualisations prompted teachers to discuss positive and negative aspects of iterative behaviour, differences between individual students, and possible intentions which may be motivating certain types of actions. The teachers generally associated the extent of iteration observed for each student with students utilising the opportunities available to experiment and "test their strategies" positively. Furthermore, the teachers sought to qualify their interpretations using the available data, going beyond a simple 'volume is good' interpretation, but seeking to understand the quality of the iterations. This included discussing the students' quality of engagement, efficiency in reaching a design, and progression between iterations.

Finally, regarding *accountability*, teachers identified five potential roles which the visualisations might have in the classroom. First, supporting the documentation and reflection process, second, generating questions to further probe students, third, tracking the impact of project design decisions, fourth, sharing the data with students and fifth, using the data for project evaluation.

The visualisations were able to expose specific aspects that teachers look for in understanding their students' iterative design behaviours and qualifying these based on the information available to reach preliminary conclusions about the students' work. The visualisations serve as a continuation of teachers' existing understanding and practices, as well as extensions into students' thinking and intentions.

8.1.4 Phase four – Reflection

Finally, as per the fourth cycle of the Design Based research methodology, we reflect on design implications that emerge from using trace data to characterise students' iterative design process through data visualisations when using physical computing kits in open-ended learning contexts.

Data visualisations as a means of exploring pedagogical concepts

Many of the learning dashboard and data visualisation designs to date focus on effective ways of conveying information to inform decisions that can change users' behaviours, towards improved learning outcomes (Lang et al., 2017). The use of activity data resulting from students' digital traces to guide pedagogical interventions is relatively recent, and dependent on a complex set of factors which influence the learning experience. These factors include the design of the learning activity, the integration of learning objectives into the digital tools available to students, the support available to students to understand and practice set learning objectives and the assessment criteria students are expected to target in their work. In the context of SAM Labs open-ended design tasks, every teacher interviewed exhibited a different way of both designing and evaluating student projects. Whilst the teachers overlapped to a large degree on the high-level pedagogical aims they targeted by engaging their students in SAM Labs construction projects, the specific implementation details of these goals in the classroom varied considerably. Whilst all teachers recognised the iterative design process as an important part of students engaging in open-ended construction tasks, the teachers used different terminology to describe it, and used distinct pedagogical frameworks to design, support and evaluate it in their classrooms. Similar variability could be observed from teachers' interpretation of the information conveyed in the visualisations. Whilst the teachers converged around related aspects to describe students' iterative behaviours, they differed in their interpretation of what the different aspects might mean for each individual student. Furthermore, the evaluation also exposed tensions inherent in all open-ended learning experiences, between efficacy and exploration, complexity and effectiveness, and simplicity and variety, all of which were exhibited in teachers' answers.

Designing learning analytics which accurately reflect the learning design is as important as acknowledging the variety present in designing for the same learning objectives, and the pedagogical tensions that exist within the learning objectives (Law and Liang, 2020). In this thesis, the goal of using data visualisations to explore the pedagogical construct of iterative design is separated from the goal of using the data visualisations directly as interventions to support students' iterative behaviours in the classroom. Whilst the visualisations' potential to be used in the classroom is explored, the visualisations are positioned as a precursor to pedagogical intervention.

Using data visualisations to explore pedagogical constructs with students and teachers can help expose the variety and tensions around specific learning objectives, as exemplified in the present research. This can lead to the design of data visualisations which accommodate for variety in learning design by separating those aspects of the learning design which are universal, and those that vary between contexts.

Data visualisations to connect students' actions to learning objectives

Our emphasis here on the process students engage in during open-ended construction tasks meant that the visualisations convey what the students do, rather than inferences from their actions. The consequence of this is twofold:

1. The teachers can relate the visualisations directly to students' actions in the classroom, which teachers reported as helpful
2. The visualisations display information students can directly act upon, rather than an abstract target separated from their activity

Simply showing students' activities is not always enough and requires being aligned with the learning design and grounded in educational theory (Martinez-Maldonado et al., 2015). Finding ways of connecting the students' activity to pedagogically meaningful constructs and exposing that relationship in a visual format can help both teachers and students better understand how their activity impacts performance. Our focus on representing students' activity furthers existing research which acknowledges students' active role in their own learning and promotes an activity-centric perspective of how users use artefacts such as SAM Labs physical computing kits (Kaptelinin and Nardi, 2006; Bødker and Klokmose, 2012).

The Distinct Approaches visualisation, in particular, teachers found useful because it contextualised the students' iterations and offered a narrative of what the iterations were and how they evolved from one another over time. Moreover, the designs were snapshots of students' constructions in time, pinpointing what the students had produced at different points during the project. Using data visualisations to connect the learning objectives teachers set out for their students to students' actions in the classroom can be an effective tool to expose students' iterative design process. Hence, they can increase the efficiency of the reflection process by directly referencing evidence from students' actions.

Data visualisations positioned to explore what cannot be inferred from the data

The visualisations' overarching goal of eliciting questions into students' intentions that cannot be inferred from the trace data. In the present research, using the appropriation model, the students' iterations are explored in relation to the functionality goals the students are trying to implement as a primary driver for the changes to their designs. The limitations of the extent to which any amount of data can expose to students' learning are well documented in the learning analytics literature (Echeverria, Martinez-Maldonado, and Buckingham Shum, 2019). Positioning data visualisations as evidence prompts for investigating specific aspects of students' learning connected to their activity and encourages a more holistic analysis of the learning experience. Rather than limiting the remit of the data visualisations to what they can expose on their own, designing them as prompts for questions helps prioritise the most important drivers for the students' actions, rather than those most suited to being quantified and visualised. This aspect of the visualisations' design aligns with a growing debate within the learning analytics community over the extent to which systems positioned to collect data on students can lead, on their own, to effective pedagogical interventions (Pardo, Ellis, and Calvo, 2015). As a response, researchers have focused on using data to encourage a more nuanced interpretation of digital footprints, to be complemented by qualitative information, accounting for the "highly complex nature of learning contexts where large number of factors are intertwined and different stakeholder can interpret the same data from different perspectives" (Pardo, Ellis, and Calvo, 2015).

Data visualisations to advance temporal analysis in learning

Finally, we explore the visualisations' role to conceptualise learning as a series of events that unfold over time, and the contribution the present research brings to the paradigm shift that temporal analysis involves (Molenaar, 2014). Specifically, the thesis provides an approach for reducing the gap between temporal trace log data collected at a micro level and the iterative design learning objective defined at a macro level (Molenaar and Wise, 2016). The data visualisations presented in this thesis aim to represent the students' iterative activity it as it unfolds over time, focusing on the ways in which students' goals evolve over the course of the project in synchronisation with their designs. In addition, dimensions are identified which characterise the way in which students iterate over time, such as the variety of solutions they attempt, the validity of solutions over time, and the complexity flow across iterations. Finally, the patterns observed from the data visualisations are indicative of the way in which the changes students make to their designs evolve over time from different perspectives: whether they converge or diverge their searches throughout the project, and the volume and timings of discarded work across the project timeline. Overall, this process-oriented approach contributes to the increase in the explanatory power of the data presented to teachers and students, helping to delve into why events occur as they do, as emerging from the teacher evaluations.

8.2 Challenges, Limitations and Future Work

The challenges encountered whilst conducting this research are presented in two categories. First, contextual limitations are presented, resulting from the environmental challenges encountered when collecting and analysing the data. Second, challenges related to the design and evaluation of the data visualisations are identified. In the process of highlighting the challenges and limitations, opportunities for future work are also identified.

8.2.1 Contextual limitations

The contextual limitations presented here are related to those conducting research in authentic "in-the-wild" classrooms with real students and teachers.

First, the researcher was limited to schools and teachers who accepted to engage with the SAM Labs kit and were willing to take part in the research project. A balancing view of the findings presented in the thesis could be offered by speaking to teachers who either did not want to engage with the research project, or those who do not view the SAM Labs kit as a useful tool for their classrooms.

Second, challenges were encountered in relation to the data collection during authentic school lessons. The researcher was dependent on the school schedule in terms of when the project lessons took place, as well as facing changes to the original project plan in view of changes to the school timetable. For example, the board game project initially took place for one and a half hour weekly lessons, moved to 45-minute lessons halfway through the project, with several weeks moved or cancelled altogether due to school festivities or other subject priorities. In addition, the video-audio recording via the students' computers webcam depended on the students themselves starting the recording at the beginning of the lesson and stopping the recording before logging out at the end of the lesson. Several times, some students forgot to start some of their recording despite reminders from the teacher, and a few times forgot to end the recording before logging out of their user accounts, which resulted in the recording being lost. Finally, the students knew they were being recorded, with an unknown impact on their actions. The researcher was present in all project lessons and the students were aware of all the data being recorded on them. The long-term duration of the project and the familiarity reached between the researcher and the students in the classroom are likely to have acted as mitigating factors, however it is difficult to know the exact impact the researcher's presence and data collection had on the students' performance.

Third, issues related to the SAM Labs trace log data collection also meant that for the lessons where the SAM Labs platform did not record the students' changes due to technical difficulties, the data for those lessons was lost without any chance of recovery or repetition of the same part of the project. For example, the SAM Labs development team initially coded the saving of the students' design changes to only start once the students assigned a name to their project in the SAM Labs interface. This meant that, for the first two lessons, where students forgot or avoided naming their SAM Labs projects, the changes they made to their designs were lost. This bug was corrected in subsequent releases of the tracking software. On two further occasions, the SAM Labs server connection malfunctioned, which also resulted in lost trace data during those lessons.

Fourth, the researcher was limited in terms of what data could be gathered, having to accommodate the structure the teacher set out for the project plan. For example, the researcher would have liked to collect student questionnaire answers around the students' perceptions of the iterative design process they engaged in, but this was not accepted by the teacher who thought she was already asking the students to document enough through the digital journals.

Finally, a fifth contextual challenge consists of the scale of the research. The student cohort was limited to three classrooms of 12-15 students (both girls and boys) in the first learning context, and 12 students (only boys) in the second learning context. Within the time and resource limitations, only the data from the second learning context was used for the main collection and analysis stage of the research. In addition, the pedagogical aspects of the context were designed by a single teacher. Whilst this contextual limitation was partially mitigated by extensions of the field work at the beginning of the research in three different schools, and the evaluation of the data with ten distinct teachers, the ability to generalise the findings to other contexts is limited without further investigation.

The five contextual limitations presented above offer opportunities for further research, expanded to a greater breadth of teachers and projects to inform the data analysis following the initial directions offered by the present research. A larger-scale research project could potentially mitigate some of the data recording challenges, expand the scope of the data collection, and better balance the variety of learning contexts and participants.

8.2.2 Data visualisations design limitations

The second category of limitations considered here is related to the design and evaluation of the data visualisations.

The visualisations were designed using a quantitative ethnography methodology to map from the low-level data available in the trace logs to the high-level educational constructs of iterative design and appropriation, as outlined in Chapter 5.

The set of data visualisations designed as part of the research are prototypes with compromises made in terms of usability and presentation. The visualisations were a result of the researcher's understanding of initial requirements as emerging from the first learning context, and prototyped into a set of visualisations to be evaluated by teachers. The teachers were not involved in the visualisation design process directly. Furthermore, the time available to the researcher to design and implement the prototypes focused on the content intended to be explored through the visualisations, rather than refining the style in which the content was presented. Whilst it is difficult to separate between content, style and intuitiveness of the information presented in the visualisations, the researcher focused on the question of "what information to show" rather than "how best to show information". In addition, the analysis focused on using the visualisations to elicit a conversation about what iterative design might be relevant to teachers, as a first step that can subsequently contribute to improving the way in which the identified aspects come through in the visualisations in the most intuitive and helpful way for teachers to act upon. In our view, the questions of style and presentation are best addressed after an initial evaluation with users, to allow the refinements to be driven by what the teachers want to see. This limitation presents a future research opportunity to co-design an improved set of visualisations with teachers, using participatory methodologies, building on the aspects of the iterative design process identified in the present research.

Second, the evaluation was aimed at teachers and experts already familiar with SAM Labs functionality, to focus the interviews on aspects of students' iterative design rather than the basic workings of SAM Labs. Whilst this was entirely in line with the goals of the research, it represents nevertheless a limitation of the research. What remains to be further explored is both how teachers using other physical computing kits respond to these kinds of visualisations, as well as teachers who have less experience in designing and engaging in open-ended projects. Such explorations entail different research questions, testing different goals and most likely require a different research structure and methodology.

Third, the visualisations do not provide any positive or negative indicators around students' activity. This was picked up by two teachers, who mentioned thresholds and red flags as information they would expect to see in the visualisations: "What I'm looking for is red flags, when there is a pattern of behaviour that's beginning to emerge that I should be aware of..." (teacher D). This limitation is attributed in part to the early stage of the research, of understanding what dimensions make up the iterative design process and identifying the type of negative or positive indicators that might be useful. This presents an opportunity for future research to design and evaluate extended versions of the visualisations that do include such indicators.

Fourth, the visualisations required a significant time to analyse and interpret in their current format. Each teacher interview lasted over an hour, and whilst it was intentionally designed to be an in-depth conversation into the iterative design process as it emerged from the visualisations, several teachers commented on the lack of time they would have on a day-to-day basis to investigate the students' actions at the same level. Therefore, future versions of the visualisations would benefit from communicating information on the students' iterative design process more succinctly.

Finally, we discuss the challenge of measuring the impact of the visualisations in the classroom, in terms of behavioural change and impact on learning performance. The present research evaluation is limited to ten teachers' perceptions on how the visualisations would be used in the classroom. A further evaluation could focus on the impact of teachers using the visualisations in the classroom and the extent to which the availability of such tools can improve students' iterative design process. This would require a refinement of the visualisations to be designed for real-time use in the classroom, and specific ways in which they could be used for guided reflection. Finally, the impact of the visualisations could also be evaluated in terms of the changes teachers make to their learning design and project evaluation.

8.2.3 Future research

Alongside the opportunities for research arising from the limitations presented above, we identify new directions for research to further advance the main goals of the present study.

1. How can the visualisations be used to practically support the student-teacher guided reflection in classroom settings?

The first future direction for the research is the refinement of the data visualisations in line with teachers' feedback to be practically used in classrooms. Improvements would be made to both the usability, presentation and content to ensure an intuitive experience for teachers to integrate in their guided reflection practices. Building on teachers' feedback regarding the potential of using the visualisations directly with students, a refined design would account for students to be able to read and interpret their own iterative design behaviours. Furthermore, the impact of using the visualisations with students would be evaluated in terms of learning gains.

2. What makes "effective" iterative design behaviours?

The present research makes a small step towards identifying quantifiable dimensions to characterise the students' iterative design tasks in open-ended construction tasks using physical computing kits. Further research could focus on a comprehensive review of all the aspects which lead to students engaging in an iterative design process effectively, and the stages of progression students will typically go through in order to become more effective iterative designers. Identifying quantifiable ways of characterising students' iterative behaviours over time can help better understand and support the ways in which students engage in open-ended construction tasks using physical computing kits.

3. How can data visualisations support open-ended learning design in construction tasks using physical computing kits?

The task of identifying quantifiable "success criteria" for students' iterative behaviours can further be used to inform the type of activities teachers design to support students' iterative design process, to form a feedback-generating cycle of learning design improvements. Using data visualisations as a means to provide teachers with evidence-based feedback on the students' activity can help them track the impact of the changes they make in their classrooms. Such a research study would need to consider the data visualisation design requirements to link the students' activity to specific aspects of the learning design, to offer measurable evidence teachers can action. Furthermore, the evaluation would need to follow several projects in order to assess the practical impact of teachers using data visualisations to inform their learning design across time.

4. How can the approach from the present research be used to design tools which support inclusive open-ended environments more generally?

Finally, we propose a methodological future research direction, where the approach used in the context of primary school children using SAM Labs physical computing kits is deconstructed and applied to other contexts. Thus, a more generic approach of designing tools using low-level trace data to support inclusive open-ended environments which prioritise the process over end-results can be identified.

The four future directions of research presented above contribute to the wider aim of the research to use learning analytics tools to promote a "classroom culture of iteration" (Fields, Lui, and Kafai, 2019) whilst "learning by designing" (Resnick and Silverman, 2005), where the "process is the product" (Johnsey, 1995).

Appendix A

SAM Labs Components

TABLE A.1: Complete list of SAM Labs components

Name	Physical	Digital	Type	App Name	Category
Button	x		Input	Button	Hardware
Button	x		Input	Button	Hardware
RGBLED	x		Output	RGB LED	Hardware
DCMotor	x		Output	DC Motor	Hardware
Potentiometer		x	Input	Slider	Hardware
CodeModule		x	Connection	Custom Code	Behaviour
Toggle		x	Connection	Toggle	Behaviour
Tilt	x		Input	Tilt	Hardware
ServoMotor	x		Output	Servo	Hardware
Keyboard		x	Input	Keyboard	Apps
Buzzer	x		Output	Buzzer	Hardware
Camera		x	Output	Camera	Apps
Player		x	Output	Sound Player	Apps
LDR	x		Input	Light Sensor	Hardware
Counter		x	Connection	Counter	Timing
TweetIn		x	Input	Tweet In	Apps
NumberValue		x	Connection	Number	Behaviour
CycleColours		x	Connection	Cycle Colours	Behaviour
Comparator		x	Connection	Compare	Behaviour
Hold		x	Connection	Hold	Timing
TweetOut		x	Output	TweetOut	Apps
Delay		x	Connection	Delay	Timing
Text		x	Connection	Text	Apps
Filter		x	Connection	Filter	Behaviour

Vibrator	x		Output	Vibrator	Hardware
Inverse		x	Connection	Inverse	Behaviour
RotaryPot	x		Input	Dimmer	Hardware
LogicAnd		x	Connection	AND	Logic
Sequencer		x	Connection	Sequencer	Apps
Pressure	x		Input	Pressure	Hardware
Interval		x	Connection	Interval	Timing
OnOff		x	Connection	OnOff	Behaviour
IRSensor	x		Input	IRSensor	Hardware
Log		x	Connection	Log	Behaviour
Temperature	x		Input	Heat	Hardware
Content		x	Connection	Content	Behaviour
Map		x	Connection	Map	Behaviour
MorseCode		x	Connection	Morse Code	Apps
Fan	x		Output	Fan	Hardware
LogicOr		x	Connection	OR	Logic
iftttOut		x	Output	IFTTT Out	Apps
Colour		x	Connection	Color	Behaviour
FacebookOut		x	Output	Facebook Out	Apps
TriggerKey	x		Input	TriggerKey	Hardware
CycleBrightness		x	Connection	Cycle Brightness	Behaviour
Direction		x	Connection	Direction	Behaviour
SwitchDirection		x	Connection	Switch Direction	Behaviour
LogicNor		x	Connection	NOR	Logic
TimeTrigger		x	Input	Time Trigger	Timing
Relay		x	Connection	Switch	Behaviour
CycleFrequency		x	Connection	Cycle Frequency	Behaviour
LogicXor		x	Connection	XOR	Logic
Note		x	Connection	Note	Behaviour
TriggerMouse		x	Input	Control Cursor	Apps
LogicNand		x	Connection	NAND	Logic
CycleVolume		x	Connection	Cycle Volume	Behaviour
TriggerText		x	Output	To Keyboard	Apps
MidiOut		x	Output	MIDI Out	Apps
LightSensor	x		Input	Light Sensor	Hardware
MidiIn		x	Input	MIDI In	Apps
Proximity	x		Input	Proximity	Hardware

MidiMessage		x	Connection	MIDI Message	Behaviour
Servo	x		Output	Servo	Hardware
Threshold		x	Connection	Threshold	Behaviour
CarController		x	Input	CarController	Apps
Scale		x	Connection	Scale	Behaviour
Switch		x	Connection	Switch	Behaviour

Appendix B

SAM Labs Code Club Structure

B.1 Information for the teacher

1. Overview - Description of the activity
2. Learning objectives - What does the activity teach children? What will students learn? What will they be able to do by the end of it?
3. How does it fit in the curriculum? Eg: subject specific goals, age specific goals (KS3, KS4, etc.), any other valuable learnings / teachings / outcomes?

B.2 Activity

B.2.1 Prerequisites

Preparatory Materials

What is required for students to be able to engage with the activity?

- Physical: Blocks, app, accounts, cardboard, drawing set
- Conceptual: Familiarity with the necessary blocks

Background Check

We encourage teachers to ensure that children are comfortable with necessary concepts used in this activity as scaffolding concepts of the main learning objectives. Eg: if the activity uses electronic circuits, do the students have any previous electronics knowledge? Do they understand what electric current is? Do they grasp that electric current can flow? Have they heard of semiconductors before?

Exploratory Questions

Now to the main learning objective of the activity. What do children already think the activity is about? Have they encountered it before? What are the questions you would like them to ask and answer for themselves during the activity? Why is this important and where does this activity contribute? How does this link to other related projects they've done? Where could this be applied? Have they had to solve any similar problems before? Brainstorming activities about its meaning, significance, contexts and related ideas.

Concept Introduction

We encourage teachers to explain the concept through verbal instruction / video / preparatory reading before the activity to introduce the students to the main ideas making up the learning objective. We encourage teachers to present the purpose and meaning of the concept - why is it important to know it and how it fits into the bigger picture of the subject.

B.2.2 SAM Activity

Instructions

SAM video and SAM activity schema shared with each student or each group of students.

Guidance and Support

Helpful prompts for students, helpful questions that draw the students' attention to specific elements of the activity. Circle back at the brainstorming done in the exploratory phase before the start of the activity - is the task answering / confirming any of the ideas brought up?

Freedom

Enough freedom for the children to express their own ideas and interests, allowing them to engage better with the activity at hand.

B.2.3 Follow-up

Reflection Questions

Encourage children to reflect on the activity just finished. What did they learn? How did the findings during the activity match up to the expectations beforehand? How do their ideas compare to the brainstorming session in the exploratory phase?

Other examples

Look at other examples of the same concepts in the same or different contexts. Where it's been used or how it's been used. How are they similar or different ?

Subject Questions

Ask children questions around the learning objectives. Consolidate their understanding, ensure the activity has reached its purpose in terms of learning objectives, get them inspired to look further to extensions of the topic.

Homework

Write about the activity, or repeat the activity, or remix the activity, or apply the activity in a different context, or identify certain aspects contained within the activity.

Related Activities

Other SAM related activities - extensions or cross-context.

Appendix C

Keble Prep School Year 7 Intelligent Board Game Project Design

Intelligent Board Game 2017-18

Introduction	Learning Expectations	Comp/DT POS	Translation of POS
Pupils are set the task to design and make a prototype board game which contains 'intelligence' – for example it is able to sense the player's pieces on the board and creates lighting or sound effects which contribute in some way to the playing of the game. They can research games already available to gain some ideas, but must come up with an idea for a game which will help other pupils revise for their history exam at the end of term. They can use 2D/3D computer-aided design(CAD) packages in order to develop designs for component parts e.g.counters/players and the board and use computer aided manufacturing (CAM) including 3D printers to make it. They can build in sensor triggers (input) and LEDs, or other outputs which are connected and controlled through the Sam app. Pupils should create an original board game project in which Sam Blocks are a central feature, the rules of their board game are clearly explained and the pupils should be able to explain	Understand the concept of 3D printing and the basic functions of 3D printer Use a computer program to create a fairly accurate 3D representation of a more complex design. (e.g. has a number of curved sides, made up of multiple parts) Using research, come up with a possible solution for a problem, and use prototypes to develop the best design possible. Then evaluate it. Understand how more advanced electrical and electronic systems can be powered and used in their products [for example, circuits with heat, light, sound and movement as inputs and outputs] Build and develop a products that incorporate systems that make use of for example, sensors to detect heat, light and sound, and control movement using simple actuators such as motors..	• Develop and communicate design ideas using …3-D and mathematical modelling, … and digital presentations and computer-based tools' • Select from and use specialist tools, techniques,processes, equipment and machinery precisely,including computer-aided manufacture' • Investigate new and emerging technologies' • Apply computing and use electronics to embed intelligence in products that respond to inputs[for example, sensors], and control outputs[for example, actuators], using programmable components [for example, microcontrollers] • Uses a range of operators and expressions e.g. Boolean, and applies them in the context of program control. • Use research and develop design criteria to inform the design of innovative, functional, appealing	Through programming and controlling physical systems, D&T offers real, relevant and practical contexts for pupils to develop and apply both computational thinking and coding skills. Creating programs in order to control products that pupils have designed and made themselves is a highly motivating, tangible experience, enabling them to test out and develop their capability in computer science within a range of authentic contexts.The application of computer science enhances learning in D&T by challenging pupils to improve the effectiveness of their products. Importantly, it has the potential to ensure that what pupils design and make in the classroom reflects the design and technology they encounter in the wider world – at home, in school, and in industry. As part of everyday life, pupils come into contact with hi-tech products that are controlled by computers, including embedded microprocessors. Both computing and D&T can build on these

their use of Conditionals,Booleans, and logical operators. In computing lessons so far, pupils have mainly up to this point learned to programme using Scratch a visual programming language to control actions. In this project they will focus on development of physical computing skills to control output.	Demonstrate understanding of conditionals, Booleans, and logical operators in an everyday situation Demonstrate an understanding of the iterative design process	products that are fit for purpose, aimed at particular individuals or groups • Understand and use electrical systems in their products [for example, series circuits incorporating switches, bulbs, buzzers and motors] • Apply their understanding of computing to program, monitor and control their products	experiences to prepare pupils adequately for later life. In this project pupils are encouraged through a project based learning approach to develop an understanding of how computer aided design can help to produce innovative, functional and appealing games which can help with revision. That it is possible that a computer can control and enhance an everyday product. Using software to help design pieces for their game it is hoped the pupils will have a real outlet to develop their skills. By including computer controlled aspects to their game it is also hoped they will have a project which will inspire them to develop their understanding of control and its possibilities.
Outcome	**Resources**	**Progression**	**Suggested Links**

To create a working prototype of a game which is enhanced by an element of ' intelligence '.	Tinkercad Thingiverse 3D printer and resources Sam Labs App and bluetooth blocks	Further Stem work. Go on to create further 3D printable objects to enhance their Sam Labs projects Working with Microbits and using these to compare with Sam Progress to text based programming using Swift using knowledge of Sam to reinforce understanding of conditions, Booleans and logic	Maths: Pupils apply skills from maths work in the domains of measurement and geometry. Science:opportunities to link this unit to work on properties and changes of materials, History : Facts about Tudors

Contents

Core Steps		Resources

Step 1- Introduction	Discuss the learning objectives of the project then proceed to lay out the challenge Challenge : Pupils create a board game project in which Sam blocks are a central feature, and their board game can use inputs, outputs, conditionals, booleans and logic operators where necessary. The task is to design and make a prototype board game which helps the user to learn about The Tudors and ideally can be used for revision by other pupils at the end of the term exam. It should be enhanced by 'intelligence' – for example it is able to sense the player's pieces on the board and at random create lighting or sound effects which contribute to the enjoyment while playing of the game. Pupils will need to work together to come up with: • A set of written rules (how to play) • A game board • A plan for Sam blocks on the canvas • Photo documentation of the different game pieces, cards, or other components of the game with the Sam blocks as well as a screenshot of the blocks on the canvas . Each photo must have a caption that describes what the photo is documenting. • Reflection: An entry in their Seesaw learning journal at the end of each lesson describing the team's game making process and each teammate's part in the creation of the game from brainstorming ideas, through construction, programming, and beta testing. The Sam Blocks need to work in conjunction with the board game and should be a central feature of the game. Ideally, it should be more than a simple substitute for a six-sided die." **Introduction :**	Sam Labs website and blocks Internet to research intelligent games already available Autodesk - TinkerCad 3D design software 3D printer Seesaw

	Discuss the task and think about what 'intelligent' means. Look at the Sam Labs website and on the IWB bring together, on a mind map, some of the boys ideas to demonstrate the task. Explain that there will be time constraints and the pupils may need to complete some of the task in after school club or at lunch time as the project needs to recorded and an accurate record of their learning journey kept in Seesaw for assessment and peer to peer evaluation. Explain they can use 2D/3D computer-aided design (CAD) packages in order to develop designs for component parts e.g.counters/players and the board and use computer aided manufacturing(CAM) including 3D printers to make it. They can build in sensor (input)and LEDs, buzzers, motors, sound player etc (output) which are connected by bluetooth to the Sam app allowing them to control the game In this project they will develop and test the program required to operate the game board as described in their specification. Make sure pupils are aware that the game must be a way of making revision of the Tudors more interesting and that this is the main aim of the game. Technology is there to enhance that experience. The Tudor facts will be supervised by Mrs Conlon during the project in her History lessons and can be added to the game at the end of the project. The main point of this project is to explore how to make the process of revision more engaging by adding an element of technology. Mrs Conlon will be asked to judge the games at the end of the project and with the pupils choose which games encouraged pupils to learn facts and made it engaging.	

Step 2: Learning how to use the design tools Sam TinkerCad/ Thingyverse	As an introduction to the challenge we will need to start by making sure the pupils are able to use the design tools - 3D printer software and Sam Blocks. There will need to some short skills lessons undertaken before the main project can start. As time is limited this will be approximately 3 or 4 lessons on each design tool. Any further refining of the skills needed to manipulate these tools will occur during the project. Explain that we will be using the Sam app which is already installed onto the desktops. Firstly we will need to spend time making sure we know how to use the app and this will include going through 2 tutorials one which covers *design* principles and one which looks at *speed*. Before looking at the tutorials on the IWB open up the SAM software and discuss Do they remember what the different blocks do ? Discuss inputs and outputs and sensors and make sure the pupils understand the difference. Go over the interface of the app and discuss what some of the software blocks do. Once the pupils have revisited the software allow them to watch the tutorials mentioned above. At the end of the tutorials discuss with the pupils some of the interesting things they have come across looking at the tutorials. Try and get them to point out how the demonstrator uses a paper pad and always begins by drawing out his circuit / flowchart before he starts. This is very good practice and reinforce this point. *All groups will need to do this before they start their work and keep a record of it taking a photograph for their Seesaw portfolio.* Once the tutorials have been covered pupils will work through some short tasks in a number of lessons to develop their understanding of how the Sam blocks and software works.	***Resources*** ***Design cycle -*** ***http://mypdesign.weebly.com/design-cycle.html*** ***http://www.bbc.co.uk/webwise/guides/about-bluetooth*** **https://www.samlabs.com/** **Tutorials** ***Design*** **https://www.samlabs.com/projects/f710d02b-2208-4ff1-917e-341f396bed9f** ***Speed*** **https://www.samlabs.com/projects/61cd4266-af4e-4a5a-8d57-6b71d8251b1b**

	Once pupils have spent some time working with Sam a few lessons will needed to be given to working with TinkerCad to learn the basics of using the software to design. Each lesson should end with reflection and journal if possible **Reflection :** Example of type of reflection How did the man in the tutorial organise his ideas ? What software blocks have you learnt during your skills session? Discuss some of the boys' comments and explore their understanding **Journal :** • What have I learnt today. Try and document any skills you have picked up.	

Step 3: Breaking game down into elements

Introduction:

As time will be limited and the pupils are Year 7 and early key stage 3 the project will need to be scaffolded a little more and not completely open. By breaking the game down into elements the pupils can work on each element separately and then at the end produce a game. Introduce the idea of iterative design.

Each elements design can be improved by testing, feedback, design development and evaluation, until a final refined / developed design is reached.

Get the pupils to discuss why do we revise what is the point ? What would help people to revise Tudor facts. How might they revise at home. What do they know about revising ?

Hopefully pupils will bring up ideas like getting someone to ask questions that you answer like a quiz. Recording your questions and answers. Making flash cards. Mind mapping, reading through their work.

Taking suggestions how might a board game mimic some of those techniques ? Discuss ideas.

Pupils will need to think of the number of players. Will be a single player or for 2 or more players. This will affect the design considerably.

Activity : Brainstorm ideas and create design specification

Give the pupils time to do some research and draw a mindmap of their ideas for a board game

Explain to the pupils they will need to think about their design and try and identify and solve their own design problems and keep a record of the process. **This is a design brief and specification.**

Resources

Go through what a design brief is

The Design Brief is a short statement of what you are going to make, why you are going to make it, and for whom you are making it for.It should be an open ended statement.

I need to create an intelligent board game which is fun to play and educational. It will help pupils in year 7 revise facts about the Tudors for their exam at the end of term .

A design specification is a list of requirements that your design ideas must meet plus a list of constraints that you have. It is the checklist that you need to use when you start to make your design ideas.

After your research you can develop a Design Specification. This will tell you:

1. The Audience- Who you are designing for (who will use the product)
2. Objective - What the successful design must do:

   This is a description of what the solution will accomplish. It could indicate how well the solution is expected to work or under what conditions it will work.

3. Production -
   - What it should look like (Size/colours/etc)
   - What it should be made from
   - Tools/software needed to make the product
   - Time needed to complete the product
4. Usage - How it will be used

Reflection:

	Discuss with pupils what kind of brief and specifications they came up with. Airplay some of the groups examples and get the pupils to comment on them. Why is a design specification a good idea to use ? How might it help with designing their game? Give pupils time to adapt their design specification and ideas in light of reflection **Journal :** Pupils should upload their design brief and specification into Seesaw the answer the questions below. ● What is a design brief ?. ● What is a design specification ? ● What was the hardest part of your specification to figure out ? ● Did you change your design specification and idea after feedback ? If so what did you change? Why?	

	Introduction : Go through with the pupils the different steps needed to complete their designs explaining the things they need to record and why. Explain the criteria that will this be used to evaluate their design. **Activity : Design the look of your board game** This step may take a few lessons and should not be rushed. Allow the pupils time to discuss and sketch out ideas for the look of their board game. Then once the pupils have decided on a design/designs give them time to evaluate their designs against their design specs they created last lesson and decide on their final choice. **Reflection:** Get students to airplay their ideas onto the IWB and explain their board design to the group. After the reflection give students opportunity to get other people from the class to look at their design and comment on it. After feedback give the pupils time to adapt their board design if necessary Put the following steps up for them on the IWB or Edmodo to follow as guidelines **Design a Product**	**Resources** DT progression pathways **Criteria B: - Design** **DT progression pathways** *Develop detailed design specifications to guide their thinking/use research to identify and understand user needs/ identify and solve their own design problems* Google docs Seesaw

	1. Create colourful designs for your board 2. Using your iPad upload these onto SeeSaw 3. Copy your Design Specification on to a new google doc and use it to **evaluate** your designs. 4. Explain your choice of final design (which is best and why) 5. Upload your finished Google doc post it on Seesaw **Journal :** Explain how you decided on your particular board design. Did drawing out your ideas, your design specification and evaluating your designs help you decide which design would be the best ? Why ?	

Introduction :

What will their player look like . Will each player have a model to represent them as they move around the board?
If so will it be a theme ? If it is a tudor revision aid how might they reflect this in the choice of player representation?

Activity : Get the pupils to draw out sketches of their player design and create a 3D player representation

Once sketched out. Post photos of the sketches onto Seesaw and get feedback from other pupils and Mrs Conlon on their designs.

After feedback and possible adaption of the ideas get the pupils to try and create their designs in TinkerCad and print off their player pieces

Reflection :

How did they find the process of sketching their ideas and getting feedback before they created their final design in TinkerCad and print it off.

Did they change their ideas during the process

Journal :

Post images of your TinkerCad design work and your final 3D print
Explain what you have done today

Resources

TinkerCad

3D printer

Google docs

Seesaw to post work for feedback

Criteria D: Create
DT Progression Pathways
exploit the use of CAD/CAM equipment to manufacture products, increasing standards of quality, scale of production and precision

Did you change your design after feedback ? If you did explain what you changed from your initial design and post your new sketch etc

Introduction:

How will the player know how to move about the board. The students will need to think about this. Will it be similar to the dice idea. Or can they think of a better way.

Explain that this would be an opportunity to introduce an element of technology or intelligence.

Activity : Design a way to move around the board

Allow the pupils to research and brainstorm ideas using Sam to design a way for the players to move around the board. It may be that the pupils design a method which allows a random way of choosing an arbitrary amount of squares the player moves or it could be they come up with a different idea. It must however be controlled by the computer and not be a 3D printed dice .They should be given the freedom to test out their ideas with their board design and get feedback either directly from other groups testing or by posting their ideas on Seesaw.

Pupils should be encouraged to take images of the different stages of their ideas both of the Sam canvas and the moving model

After feedback and testing they should be encouraged to adapt their ideas and refine it until they are happy.

Reflection :

Ask pupils to airplay their plans and share them with the rest of the class.

	What went right right or wrong and how did you solve the problems Does it help seeing other groups planning ? Did you go back and improve or change your planning after getting feedback ? **Journal :** What did you learn this lesson ? Have you improved your ability to design a solution using Sam? Have you you learned how to use the software blocks in a new way to create your solution? Did planning your means of moving your player, getting feedback, adapting your ideas help you refine your idea ? Did you have to solve a problem to make your design work and if so how ? How might this improve your planning in future ?	

	Introduction : **Problem : How will your player /players play the game ?** Will they be asked questions ? How will these questions be delivered ? By card, by the computer ? When will they be asked the questions ? How will they know if they have got the answer right ? What is the end point of the game ? Does it involve a score ? This section will again give the pupils the opportunity to introduce elements of technology and design into their game. Pupils should be given the time to brainstorm their ideas and test out their ideas and refine them. They should be encouraged to seek out feedback until they are happy with their solutions. This is a time pupils can have extended time to really think about their ideas and keep evolving their idea until it works by debugging and testing.It may be at this point more 3D printable solutions also present themselves as the ideas develop. Allow the pupils chance to explore every idea they wish. Allow pupils to create any elements needed to make these work. **Journal** Encourage them to record all their developments and ideas successful and unsuccessful with explanations of what went right , what went wrong and how they solved problems.	**Resources** **Seesaw to post work for feedback** **Sam App** **Tinkercad and 3D**

Step 3 : Creating your finished Game	**Reflection :** Allow pupils to lead discussions about their game so far and demonstrate or project evidence of their work and explore feedback comments. Time should be given to any group who wishes to refine their ideas after reflection. **Introduction:** Time should be given to put all the pieces of their game together and actually completely make their finished design. Again the pupils should be encouraged to adapt they design if feedback throws up any issues. The design can be evolving at any time. At this point pupils should be focusing also on the presentation of the game and how it will look and creating clear rules and instructions. **Activity : Putting all the pieces together and creating your game** Pupils should have access to all the modelling materials, the 3D printer and Sam blocks and given the time to finish off their design and create their finished game. **Reflection and Journal:** Ask the pupils to reflect on creating the project	**Resources :** **Pizza boxes , paint , pens , modelling products , 3D printer , Sam blocks** **Seesaw**

	• What was something that was surprising to you about the process of creating this game? • Describe a difficult point in the process of designing this game, and explain how you resolved it. • What new skills do you feel you have learnt ? • Reflecting back on the learning objectives from the start of the term which do you feel you have achieved ?	

Step 4: Evaluate	**Introduction:** Explain to the pupils once the game has been created the final stage needs to be evaluating the design. Explain that this part of the project is important and brings the project together allowing the group to reflect on what they have learnt and get feedback to all their hard work. It is important to have final user testing or Beta testing as this step can help the creator spot things they might have missed before any product goes live. Pupils can use this to make some final changes and tweaks. Give the pupils the Evaluate specifications via Seesaw so they can use it as a check list. Explain about Beta testing 3 students will test your game. You will post an image of your game onto seesaw and add a google form for them to complete. The form/survey questions are How easy was it to figure out what to do? What is something about this project that works really well? What is something that would make this project even better? Any other comments or suggestions? **Evaluate :** 1. **User Trial/ Beta testing :** Have **3** other students played your game and get their feedback by posting an image on seesaw and asking them to comment on it below using the google form 2. Make any changes prompted by your feedback 3. Reflect on your **own learning**. What did you do well and how could you improve next time. 4. Create a google doc called **Evaluate My Game** and Insert a photograph of your finished game onto your Evaluate page. Copy the **Design Specification** and use it to evaluate your finished game 5. When finished upload your google doc into seesaw	**Seesaw** DT progression pathways Criteria E: Evaluate your design *evaluate their products against their original specification and identify ways of improving them* *actively involve others in the testing of their products*

Level	Criteria E: Evaluate your design *evaluate their products against their original specification and identify ways of improving them* *actively involve others in the testing of their products*	Our Criteria E: Evaluate your design **Keble's interpretation**
basic	You have commented the success of the product/solution or your own performance.	You have made some comments about your game and/or have included the comments from other students.
Good	You have considered the success of the product/solution and your own performance and suggested ways in which these could be improved. You have compared the final product/solution against some of the design specification requirements.	You have evaluated your game using the design specification and have a few user trials. You have made suggestions about how to improve your game and your own learning.
Better	You have considered the success of the product/solution based on the results of testing and your own views. You have provided an evaluation of your own performance at different stages of the design cycle and suggested improvements. You have provided some evaluation of the impact of the product/solution on individuals and/or our community.	You have evaluated your game using the design specification and have a several user trials. (with photos) You have made suggestions about how to improve your game. You have reflected upon your own leaning (with ways to improve) and how well you have met the design challenge.

Reflection:

Ask the pupils to return to what they think makes a good game. This might have changed from their original ideas having gone through the process. Record their ideas and thoughts on the IWB. Link their ideas of what makes a good game to the process of making a game and the stages they went through.

	Should a game designer have gone through the stages you went through ? Could going through the stages help the designer refine his ideas ? Is Beta testing important? Go through the criteria used to assess how they have evaluated their game and explain it and get the pupils feedback. Journal: ● What feedback did your beta testers give you? How did that help you improve your game? ● What do you think you have learnt during this project ? ● Did using technology help you create a more interesting game ? How did it enhance the game and the user engagement ? ● What might you do differently if you could start again?	

Appendix D

Jupyter Notebooks

```
Blocks and Connections

#!/usr/bin/env python
# coding: utf-8

# In[1]:



import pymysql.cursors
connection = pymysql.connect(host='localhost',
                                     user='user',
                                     password='password',
                                     db='samlogs',
                                     charset='utf8mb4',
                                     cursorclass=pymysql.cursors.DictCursor,
                                     autocommit=True)

#try:
with connection.cursor() as cursor:
    print(cursor.execute("SELECT distinct invalid_reason FROM samlogs.directedgraphs"))

project_path = "project_path";

project_folder = "project_folder";
projectID = ('projectID',);

#one project
parameters = (projectID,);
```

```
#2 or more projects
#projectID2 = ('projectID2',);
#parameters = (projectID,projectID2,);


# In[2]:


with connection.cursor() as cursor:
    #one project
    cursor.execute("SELECT projectID,stateID,timeCreated,nodeID,nodeName _
                   FROM samlogs.nodes WHERE projectID = %s _
                   ORDER BY timeCreated", parameters);

    #2 or more projects
    #cursor.execute("SELECT projectID,stateID,timeCreated,nodeID,nodeName _
                   FROM samlogs.nodes WHERE projectID in (%s,%s) _
                   ORDER BY timeCreated", parameters);

    result_nodes = cursor.fetchall();
    print((result_nodes));


# In[3]:


with connection.cursor() as cursor:
    #one project
    cursor.execute("SELECT DISTINCT nodeName _
                   FROM samlogs.nodes WHERE projectID = %s _
                   ORDER BY timeCreated", parameters);

    #two or more projects
    #cursor.execute("SELECT DISTINCT nodeName _
                   FROM samlogs.nodes WHERE projectID in (%s, %s) _
                   ORDER BY timeCreated", parameters);

    result_dist_nodes = cursor.fetchall();
    print(len(result_dist_nodes));

#node_names_set = set(result_dist_nodes);
```

```
node_names_set = set();
for item in result_dist_nodes:
    if item['nodeName'] is not '':
        node_names_set.add(item['nodeName']);

print(node_names_set)


# In[4]:


with connection.cursor() as cursor:
    #one project
    cursor.execute("SELECT projectID, stateID, fromID, _
                   toID, CONCAT(fromID, '->', toID) as fulledge _
                   FROM samlogs.edges WHERE projectID = %s _
                   AND fromID <> '' AND toID <> '' _
                   ORDER BY timeCreated", parameters);

    #2 or more projects
    #cursor.execute("SELECT projectID, stateID, fromID, toID, _
                   CONCAT(fromID, '->', toID) as fulledge _
                   FROM samlogs.edges WHERE projectID in (%s,%s) _
                   AND fromID <> '' AND toID <> '' ORDER BY timeCreated", parameters);

    result_edges = cursor.fetchall();
    print(len(result_edges));


# In[5]:


inputs = ['Button', 'Potentiometer', 'Tilt', 'Keyboard', 'LDR',
          'TweetIn', 'RotaryPot', 'Pressure', 'IRSensor',
          'Temperature', 'TimeTrigger', 'LightSensor',
          'Proximity', 'CarController', 'TriggerKey',
          'TriggerMouse', 'ProcessingIn', 'MidiIn', 'Accelerometer',
          'GPS', 'IPhone', 'SensorActorProto', 'Joystick'];

outputs = ['RGBLED', 'DCMotor', 'ServoMotor', 'Buzzer',
           'Camera', 'Player', 'TweetOut', 'Vibrator', 'Fan',
```

```
           'TriggerText', 'iftttOut', 'FacebookOut', 'DigitalOut',
           'MidiOut', 'ProcessingOut', 'HueLight', 'Servo', 'Say',
           'Drone', 'Nest', 'TwoMotors', 'Sonos', 'Tesco', 'AnyIO',
           'LeapMotionSwipe', 'LeapMotionPosition', 'LeapMotionHand',
           'Sphero', 'LeapMotionCircle', 'MqttOut'];

connections =['CodeModule', 'Toggle', 'Counter', 'NumberValue',
              'CycleColours', 'Comparator', 'Hold', 'Delay', 'Text',
              'Filter', 'Inverse', 'LogicAnd', 'Sequencer', 'Interval',
              'OnOff', 'Log', 'MorseCode', 'LogicOr', 'Colour',
              'CycleBrightness', 'Direction', 'SwitchDirection',
              'LogicNor', 'Relay', 'CycleFrequency', 'LogicXor', 'Note',
              'LogicNand', 'CycleVolume', 'Threshold', 'Scale', 'Switch',
              'Content', 'Map', 'CloudWifi', 'MotorMovement', 'Cloud',
              'MidiMessage', 'Ultrasonic', 'DotMatrix', 'Serial',
              'MIC', 'Inspect', 'StateMachine', 'IMU', 'AmplifyNum'];

print(inputs); print(outputs); print(connections);


# In[6]:


edge_names = [];

for edge in result_edges:
    fromNodeID = edge['fromID']; toNodeID = edge['toID'];
    fromNodeName = [item['nodeName'] for item in result_nodes if item['nodeID'] == fro
    toNodeName = [item['nodeName'] for item in result_nodes if item['nodeID'] == toNod
    #print(fromNodeName); print(toNodeName);
    if (len(fromNodeName)) > 0 and (len(toNodeName) > 0):
        edge = (str(fromNodeName[0]), str(toNodeName[0]));
        edge_names.append(edge);

edge_names_set = set(edge_names);

edge_weights = {};
for edge in edge_names_set:
    edge_weights[edge] = 0;

for edge in edge_names:
```

```
    edge_weights[edge] = edge_weights[edge] + 1;

edge_names_weights = [];
for edge in edge_names_set:
    edge = edge + (edge_weights[edge],);
    edge_names_weights.append(edge);

print(edge_names_set)
print(edge_weights)
print(edge_names_weights)


# In[7]:



nodes = {};
node_properties = {}; # 'label', 'colour', 'pos' = (x,y)

no_of_inputs = 0;
no_of_outputs = 0;
no_of_conns = 0;

for node in node_names_set:
    if node in inputs:
        no_of_inputs = no_of_inputs + 1;
    if node in outputs:
        no_of_outputs = no_of_outputs + 1;
    if node in connections:
        no_of_conns = no_of_conns + 1;

max_type = max(no_of_inputs, no_of_outputs, no_of_conns);

next_ypos_inputs = 1;
next_ypos_outputs = 1;
next_ypos_conns = 1;

if no_of_inputs != max_type:
    next_ypos_inputs = int(max_type/2) - int(no_of_inputs/2) +1;
    print(next_ypos_inputs);
if no_of_outputs != max_type:
    next_ypos_outputs = int(max_type/2) - int(no_of_outputs/2) +1;
```

```
    print(next_ypos_outputs);
if no_of_conns != max_type:
    next_ypos_conns = int(max_type/2) - int(no_of_conns/2) +1;
    print(next_ypos_conns);

for node in node_names_set:
    node_properties = {};

    if node in inputs:
        pos_x = 10;
        pos_y = next_ypos_inputs;
        pos = (pos_x,pos_y);
        next_ypos_inputs = next_ypos_inputs +1;
        node_properties['colour'] = '#F0D9D9';
        node_properties['label'] = node;
        node_properties['pos'] = pos;

    if node in connections:
        pos_x = 20;
        pos_y = next_ypos_conns;
        pos = (pos_x,pos_y);
        next_ypos_conns = next_ypos_conns +1;
        node_properties['colour'] = '#FAEBC5';
        node_properties['label'] = node;
        node_properties['pos'] = pos;

    if node in outputs:
        pos_x = 30;
        pos_y = next_ypos_outputs;
        pos = (pos_x,pos_y);
        next_ypos_outputs = next_ypos_outputs +1;
        node_properties['colour'] = '#EDEDF0';
        node_properties['label'] = node;
        node_properties['pos'] = pos;

    nodes[node] = node_properties;

print(nodes);


# In[8]:
```

```
import networkx as nx
import matplotlib.pyplot as plt

plt.figure(figsize=(18,15))

G = nx.DiGraph();
G.add_nodes_from(nodes);
nx.set_node_attributes(G, nodes);
G.add_edges_from(edge_names_set);
#G.add_weighted_edges_from(edge_names_weights);

nodecolordict = nx.get_node_attributes(G,'colour');
nodecolorlist = [];
for key, value in nodecolordict.items():
    nodecolorlist.append(value);

labeldict = nx.get_node_attributes(G,'label');
pos = nx.get_node_attributes(G,'pos');

nx.draw_networkx_nodes(G, pos, node_size=6500, node_color=nodecolorlist);
nx.draw_networkx_labels(G, pos, labels=labeldict, with_labels=False)
nx.draw_networkx_edges(G, pos, arrows=True);
#nx.draw_networkx_edge_labels(G, pos, labels = edge_weights);
#nx.draw_networkx_edges(G, pos, arrows=True, width=edge_weights);

image_file = project_path + project_folder + _
             '\\' + 'Blocks used per project (layers)' + '.png';
plt.savefig(image_file, bbox_inches = "tight");
plt.show()

#nx.draw(G);
#nx.draw_shell(G);
#nx.draw_circular(G);
## NOT nx.draw_kamada_kawai(G);
## NOT nx.draw_spectral(G);
## NOT nx.draw_spring(G);


# In[8]:
```

```
import networkx as nx
import matplotlib.pyplot as plt

plt.figure(figsize=(12,8))

G = nx.DiGraph();
G.add_nodes_from(nodes);
nx.set_node_attributes(G, nodes);
G.add_edges_from(edge_names_set);
#G.add_weighted_edges_from(edge_names_weights);

nodecolordict = nx.get_node_attributes(G,'colour');
nodecolorlist = [];
for key, value in nodecolordict.items():
    nodecolorlist.append(value);

labeldict = nx.get_node_attributes(G,'label');
#pos = nx.get_node_attributes(G,'pos');
pos=nx.circular_layout(G)

nx.draw_circular(G, node_size=6500, node_color=nodecolorlist);
#nx.draw_networkx_nodes(G, pos, node_size=3500, node_color=nodecolorlist);
nx.draw_networkx_labels(G, pos, labels=labeldict, with_labels=True)
nx.draw_networkx_edges(G, pos, arrows=True);
#nx.draw_networkx_edge_labels(G, pos, labels = edge_weights);
#nx.draw_networkx_edges(G, pos, arrows=True, width=edge_weights);

image_file = project_path + project_folder + _
             '\\' + 'Blocks used per project (circular)' + '.png';
plt.savefig(image_file, bbox_inches = "tight");
plt.show()

#nx.draw(G);
#nx.draw_shell(G);
#nx.draw_circular(G);
## NOT nx.draw_kamada_kawai(G);
## NOT nx.draw_spectral(G);
## NOT nx.draw_spring(G);
```

```
# In[9]:


nodes_sequence = []; i=0;

next_input = 0;
next_conn = no_of_inputs;
next_output = no_of_inputs + no_of_conns;

for node in nodes:
    nodes_sequence.append(node);
    i = i+1;

no_nodes = len(nodes_sequence);
print(no_nodes)

plus_input = True; loop_input = 0;
if (no_of_outputs % 2) == 0:
    start_input = int(no_nodes/2);
else:
    start_input = int(no_nodes/2) + 1;
print('loop input'); print (loop_input);
print ('start input'); print (start_input);

plus_conn = True;
if (no_of_outputs % 2) == 0:
    loop_conn_up = int(no_of_outputs/2);
    loop_conn_down = no_nodes - int(no_of_outputs/2) - 1;
else:
    loop_conn_up = int(no_of_outputs/2) + 1;
    loop_conn_down = no_nodes - int(no_of_outputs/2) - 1;

print('loop conn up'); print (loop_conn_up);
print('loop conn down'); print (loop_conn_down);

plus_output = True; loop_output_up = 0; loop_output_down = no_nodes - 1;
print('loop output up'); print (loop_output_up);
print('loop output down'); print (loop_output_down);

for node in nodes:
```

```
    if node in inputs:
        if plus_input:
            nodes_sequence[start_input + loop_input] = node;
            plus_input = False;
            loop_input = loop_input + 1;
            print(node + ' loop input'); print (loop_input);
        else:
            nodes_sequence[start_input - loop_input] = node;
            plus_input = True;
            print(node + ' loop input'); print (loop_input);
    if node in connections:
        if plus_conn:
            nodes_sequence[loop_conn_up] = node;
            loop_conn_up = loop_conn_up + 1;
            plus_conn = False;
            print(node + ' loop conn up'); print (loop_conn_up);
        else:
            nodes_sequence[loop_conn_down] = node;
            loop_conn_down = loop_conn_down - 1;
            plus_conn = True;
            print(node + ' loop conn down'); print (loop_conn_down);
    if node in outputs:
        if plus_output:
            nodes_sequence[loop_output_up] = node;
            loop_output_up = loop_output_up + 1;
            plus_output = False;
            print(node + ' loop output up'); print (loop_output_up);
        else:
            nodes_sequence[loop_output_down] = node;
            loop_output_down = loop_output_down -1;
            plus_output = True;
            print(node + ' loop output down'); print (loop_output_down);


#for node in nodes:
#    if node in inputs:
#        nodes_sequence[next_input] = node;
#        next_input = next_input + 1;
#    if node in connections:
#        nodes_sequence[next_conn] = node;
#        next_conn = next_conn + 1;
```

```
#    if node in outputs:
#        nodes_sequence[next_output] = node;
#        next_output = next_output + 1;

print(nodes_sequence);


# In[10]:


import networkx as nx
import matplotlib.pyplot as plt

plt.figure(figsize=(12,8))

G = nx.DiGraph();
G.add_nodes_from(nodes_sequence);
nx.set_node_attributes(G, nodes);
G.add_edges_from(edge_names_set);
#G.add_weighted_edges_from(edge_names_weights);

nodecolordict = nx.get_node_attributes(G,'colour');
nodecolorlist = [];
for key, value in nodecolordict.items():
    nodecolorlist.append(value);

labeldict = nx.get_node_attributes(G,'label');
#pos = nx.get_node_attributes(G,'pos');
pos=nx.circular_layout(G)

nx.draw_circular(G, node_size=6500, node_color=nodecolorlist);
#nx.draw_networkx_nodes(G, pos, node_size=3500, node_color=nodecolorlist);
nx.draw_networkx_labels(G, pos, labels=labeldict, with_labels=True)
nx.draw_networkx_edges(G, pos, arrows=True);
#nx.draw_networkx_edge_labels(G, pos, labels = edge_weights);
#nx.draw_networkx_edges(G, pos, arrows=True, width=edge_weights);

image_file = project_path + project_folder + '\\' _
             + 'Blocks used per project (circular i-c-o)' + '.png';
plt.savefig(image_file, bbox_inches = "tight");
plt.show()
```

```
#nx.draw(G);
#nx.draw_shell(G);
#nx.draw_circular(G);
## NOT nx.draw_kamada_kawai(G);
## NOT nx.draw_spectral(G);
## NOT nx.draw_spring(G);


# In[11]:


with connection.cursor() as cursor:
    #one project
    cursor.execute("SELECT DISTINCT ID,path_id,path_label, _
                   valid,invalid_reason,behaviour,progressing_path_ID _
                   FROM samlogs.directedgraphs WHERE projectID = %s", parameters);

    #2 or more projects
    #cursor.execute("SELECT DISTINCT ID,path_id,path_label, _
                   valid,invalid_reason,behaviour,progressing_path_ID _
                   FROM samlogs.directedgraphs WHERE projectID in (%s,%s)", parameters

    result_circuits = cursor.fetchall();
    print((result_circuits))


# In[12]:


with connection.cursor() as cursor_time:
    #one project
    cursor_time.execute("SELECT DISTINCT ID, timeCreated, path_id, _
                        path_label,progressing_path_ID _
                        FROM samlogs.directedgraphs _
                        JOIN samlogs.nodes ON directedgraphs.stateID = nodes.stateID
                        WHERE directedgraphs.projectID = %s _
                        ORDER BY timeCreated", parameters);

    #2 or more projects
    #cursor_time.execute("SELECT DISTINCT ID, timeCreated, path_id, _
```

```
                        path_label,progressing_path_ID FROM samlogs.directedgraphs _
                        JOIN samlogs.nodes ON directedgraphs.stateID = nodes.stateID _
                        WHERE directedgraphs.projectID in (%s,%s) _
                        ORDER BY timeCreated", parameters);

    result_path_time = cursor_time.fetchall();
print(len(result_path_time));




# In[13]:



def get_previous_path_blocks(ID):

#result_path_time is an ordered list of directedindividualpaths.
#find the previous path to the given ID
#to identify whether the current path is a subset of its previous state
#(eg: the input has been removed)
#in order to get the appropriate level at which the block should be placed
#in the overall graph
#eg: current state is toggle->buzzer, but previous state is
#button->toggle->buzzer. The toggle should be placed at level2

    level = 1;
    current_path = list(filter(lambda path: path['ID'] == ID, result_path_time));
    print(current_path)
    id_index = result_path_time.index(current_path[0]);
    blocks_id = result_path_time[id_index]['path_id'];
    blocks_id_list = result_path_time[id_index]['path_id'][2:].split('->');

    if id_index > 0:
        for i in range(id_index-1,0, -1):
            if result_path_time[i]['progressing_path_ID'] == result_path_time[id_index]['pr
                previous_blocks_id = result_path_time[i]['path_id'];
                previous_blocks_id_list = result_path_time[i]['path_id'][2:].split('->');
                if previous_blocks_id.find(blocks_id) > 0:
                    new_level = previous_blocks_id_list.index(blocks_id_list[0]) + 1;
                    if new_level > level:
                        level = new_level;
```

```
    return level;

#print(get_previous_path_blocks(1187))


# In[14]:


nodes = {};
nodes_properties = {}; # 'label', 'colour', 'level', 'type', 'pos' = (x,y)
edges = {};
level = 1;
inconns_per_level = {};
outputs_per_level = {};

for circuit in result_circuits:
    blocks = circuit['path_label'][2:].split('->');
    level = get_previous_path_blocks(circuit['ID']);

    for block in blocks:
        node = str(block) + str(level);
        nodes_properties = {};
        edge_properties = {};

        if node not in nodes.keys():
            nodes_properties['label'] = block;
            if block in inputs:
                nodes_properties['colour'] = '#F0D9D9';
                nodes_properties['type'] = 'input';
                if level in inconns_per_level.keys():
                    inconns_per_level[level] = inconns_per_level[level] + 1;
                else:
                    inconns_per_level[level] = 1;
            if block in outputs:
                nodes_properties['colour'] = '#EDEDF0';
                nodes_properties['type'] = 'output';
                if level in outputs_per_level.keys():
                    outputs_per_level[level] = outputs_per_level[level] + 1;
                else:
                    outputs_per_level[level] = 1;
            if block in connections:
```

```
                nodes_properties['colour'] = '#FAEBC5';
                nodes_properties['type'] = 'connection';
                if level in inconns_per_level.keys():
                    inconns_per_level[level] = inconns_per_level[level] + 1;
                else:
                    inconns_per_level[level] = 1;

            nodes_properties['level'] = level;
            nodes[node] = nodes_properties;

        # 'weight' - set as edge width
        #if past the first node (with no 'in' edge to account for)
        if blocks.index(block) > 0:
            #print('previous_node: ' + previous_node); print('current_node: ' + node);
            edge = (previous_node,node);
            if edge in edges.keys():
                edges[edge]['weight'] = edges[(previous_node,node)]['weight'] + 0.03;
            else:
                edges.update({edge:{'weight': 0.03}});

        previous_node = node;
        #increase weight / width of edge
        level = level + 1;

print(nodes); print(edges);
print(inconns_per_level); print(outputs_per_level);


# In[15]:


no_nodes_per_level = [];
max_level_node = max(nodes, key=lambda i: nodes[i]['level']);
print(max_level_node)
max_level = nodes[max_level_node]['level'];
print(max_level)

# calculate the maximum possible number of nodes that need to be arranged
# on the x axis so that lists for each level
# can be initiated and populated on different positions at different times,
# as and when a good position in the list
```

```
# is found - either above the same type of block from the previous level
#or in the right sequence of input, connection, output
#for i in range(1,max_level+1):
#    no_nodes = 0;
#    if i in inconns_per_level.keys():
#        no_nodes = no_nodes + inconns_per_level[i];
#    if i in outputs_per_level.keys():
#        no_nodes = no_nodes + outputs_per_level[i];
#    no_nodes_per_level.append(no_nodes);

# calculate the maximum number of inputs+connections across all levels
#- that is the threshold from there
# connection blocks start going left, and outputs start going right.
#even if there are fewer inputs + conns on any given
# level, still start at the maximum number across all levels, for
#even vertical alignment and getting the connections
# as close together to the outputs as possible at every level.
max_inconns_alllevels = max(inconns_per_level.values());
print(max_inconns_alllevels)

max_outputs_alllevels = max(outputs_per_level.values());
print(max_outputs_alllevels)

max_width = max_inconns_alllevels + max_outputs_alllevels;

# initiate each list of lists with empty strings of the
#maximum possible number of nodes at each level
# so that values can be assigned in the correct position
#(with potential gaps), same type of blocks on the same vertical
# lines. if lists not initiated, I can only append to the list,
#as I'd have to append as well as potentially shuffling
# the already existing blocks in the list backwards or forwards.
nodes_per_level = [];
for i in range(0,max_level):
    nodes_each_level = [];
    for j in range(0,max_width):
        nodes_each_level.append('');
    nodes_per_level.append(nodes_each_level);
print(nodes_per_level)

# take each level of the future graph in turn. add the nodes of each level,
```

```
#in the right order, in a list of lists,
# each list representing a level. From the list they are in (level)
#and the position in that list (x axis on the level),
# set the pos of each node in the graph.
for i in range(1,max_level+1):
    print('nodes per level list: '); print(nodes_per_level);
    # in order to keep the same type of nodes in the same vertical lines,
    #for easier intepretation (toggles above toggles)
    # check at each level if there are any blocks of the same type as the previous.
    #if there are, transfer into the same
    #position as the previous level.
    for node_key, node_value in nodes.items():
        if node_value['level'] == i:
            if i>1:
                for j in range(i-2,-1,-1):
                    if node_value['label'] in nodes_per_level[j]:
                        print('transfer: ' + node_value['label'] + ' on i ' + str(i-1) + '
                        nodes_per_level[i-1][nodes_per_level[j].index(node_value['label'])]
                        break;
    # now that all the nodes of the same type have been allocated
    #the same position in the list at the relevant level,
    # as the positions on the previous level, I can now fill in the gaps
    #with the remaining nodes that were not found on
    # the previous level
    for node_key, node_value in nodes.items():
        if node_value['level'] == i:
            if node_value['label'] not in nodes_per_level[i-1]:
                if node_value['type'] == 'input':
                    for j in range(0,len(nodes_per_level[i-1])):
                        if nodes_per_level[i-1][j] == '':
                            print('add new input: ' + node_value['label'] + ' on i ' + str(
                            nodes_per_level[i-1][j] = node_value['label'];
                            break;
                if node_value['type'] == 'connection':
                    for j in range(max_inconns_alllevels - 1, -1, -1):
                        if nodes_per_level[i-1][j] == '':
                            print('add new connection: ' + node_value['label'] + ' on i ' +
                            nodes_per_level[i-1][j] = node_value['label'];
                            break;
                if node_value['type'] == 'output':
                    for j in range(max_inconns_alllevels, max_width):
```

```
                        if nodes_per_level[i-1][j] == '':
                            print('add new output after: ' + node_value['label'] + ' c
                            nodes_per_level[i-1][j] = node_value['label'];
                            break;

print(nodes_per_level);




# In[16]:



for node_key, node_value in nodes.items():
    level = node_value['level'];
    ntype = node_value['label'];
    pos_x = (nodes_per_level[level-1].index(ntype) + 1) * 5;
    pos_y = level * 5;
    pos = (pos_x,pos_y);
    node_value['pos'] = pos;

print(nodes);


# In[17]:



import networkx as nx
import matplotlib.pyplot as plt

plt.figure(figsize=(22,12))

G = nx.DiGraph();
G.add_nodes_from(nodes);
nx.set_node_attributes(G, nodes);
G.add_edges_from(edges);
nx.set_edge_attributes(G, edges);

nodecolordict = nx.get_node_attributes(G,'colour');
nodecolorlist = [];
for key, value in nodecolordict.items():
    nodecolorlist.append(value);
```

```
labeldict = nx.get_node_attributes(G,'label');
pos = nx.get_node_attributes(G,'pos');

nx.draw_networkx_nodes(G, pos, node_size=6500, node_color=nodecolorlist);
nx.draw_networkx_labels(G, pos, labels=labeldict, with_labels=True)
nx.draw_networkx_edges(G, pos, width=list(nx.get_edge_attributes(G,'weight').values()));

image_file = project_path + project_folder + '\\' _
             + 'Blocks usage per level' + '.png';
plt.savefig(image_file, bbox_inches = "tight");
plt.show()
```

Kept versus Discarded

```
#!/usr/bin/env python
# coding: utf-8

# In[1]:



import pymysql.cursors
connection = pymysql.connect(host='localhost',
                                     user='user',
                                     password='password',
                                     db='samlogs',
                                     charset='utf8mb4',
                                     cursorclass=pymysql.cursors.DictCursor,
                                     autocommit=True)

#try:
with connection.cursor() as cursor:
    print(cursor.execute("SELECT distinct invalid_reason FROM samlogs.directedgraphs"))

project_path = "project_path";

project_folder = "project_folder";
projectID = ('projectID',);

#one project
```

```
parameters = (projectID,);

#2 or more projects
#projectID2 = ('projectID2',);
#parameters = (projectID,projectID2,);


# In[2]:


with connection.cursor() as cursor:
    #one project
    cursor.execute("SELECT projectID,stateID,path_id,path_label, _
                   valid,ID,progressing_path_ID _
                   FROM directedgraphs where projectID = %s", parameters);

    #2 or more projects
    #cursor.execute("SELECT projectID,stateID,path_id,path_label, _
                   valid,ID,progressing_path_ID _
                   FROM directedgraphs where projectID in (%s,%s)", parameters);

    result_paths = cursor.fetchall();
    print(len(result_paths));


# In[3]:


with connection.cursor() as cursor:
    #one project
    cursor.execute("SELECT projectID,stateID,timeCreated,nodeID,nodeName _
                   FROM samlogs.nodes WHERE projectID = %s _
                   ORDER BY timeCreated", parameters);

    #2 or more projects
    #cursor.execute("SELECT projectID,stateID,timeCreated,nodeID,nodeName
                   #FROM samlogs.nodes WHERE projectID in (%s, %s)
                   #ORDER BY timeCreated", parameters);

    result_nodes = cursor.fetchall();
    print(len(result_nodes));
```

```
# In[34]:


with connection.cursor() as cursor:
    #one project
    cursor.execute("SELECT projectID, stateID, fromID, toID, _
                   CONCAT(fromID, '->', toID) as fulledge _
                   FROM samlogs.edges WHERE projectID = %s _
                   ORDER BY timeCreated", parameters);

    #2 or more projects
    #cursor.execute("SELECT projectID, stateID, fromID, toID,
                   #CONCAT(fromID, '->', toID) as fulledge
                   #FROM samlogs.edges WHERE projectID in (%s,%s)
                   #ORDER BY timeCreated", parameters);

    result_edges = cursor.fetchall();
    print(len(result_edges));


# In[4]:


with connection.cursor() as cursor:
    #one project
    cursor.execute("SELECT DISTINCT fromID, toID, CONCAT(fromID, '->', toID) _
                   as fulledge FROM samlogs.edges WHERE projectID = %s _
                   AND fromID <> '' AND toID <> '' _
                   ORDER BY timeCreated", parameters);

    #2 or more projects
    #cursor.execute("SELECT DISTINCT fromID, toID, CONCAT(fromID, '->', toID)
                   #as fulledge FROM samlogs.edges WHERE projectID in (%s,%s)
                   #AND fromID <> '' AND toID <> ''
                   #ORDER BY timeCreated", parameters);

    result_unique_edges = cursor.fetchall();
    print(len(result_unique_edges));
```

```
# In[5]:


with connection.cursor() as cursor_time:
    #one project
    cursor_time.execute("SELECT DISTINCT timeCreated, directedgraphs.stateID _
                        FROM samlogs.directedgraphs JOIN samlogs.nodes _
                        ON directedgraphs.stateID = nodes.stateID _
                        WHERE directedgraphs.projectID = %s _
                        ORDER BY timeCreated", parameters);

    #2 or more projects
    #cursor_time.execute("SELECT DISTINCT timeCreated, directedgraphs.stateID
                        #FROM samlogs.directedgraphs JOIN samlogs.nodes
                        #ON directedgraphs.stateID = nodes.stateID
                        #WHERE directedgraphs.projectID in (%s, %s)
                        #ORDER BY timeCreated", parameters);

    result_statetime = cursor_time.fetchall();
    print(len(result_statetime));


# In[6]:


unique_timeCreated = [ item['timeCreated'] for item in result_statetime ]
unique_timeCreated.sort();
#print (unique_timeCreated);
print(result_statetime[len(result_statetime)-1]['stateID']);


# In[7]:


final_state_edges = [item['fulledge'] for item in result_edges if item['stateID'] == r
print(len(final_state_edges))


# In[8]:
```

```
unique_state_edges_order = [];
unique_state_edgeblocks = [];
up = 0; down = 0;

for edge in result_unique_edges:
    fromNodeID = edge['fromID']; toNodeID = edge['toID'];

    fromNodeName = [item['nodeName'] for item in result_nodes if item['nodeID'] == fromNode
    toNodeName = [item['nodeName'] for item in result_nodes if item['nodeID'] == toNodeID];
    if (len(fromNodeName)) > 0 and (len(toNodeName) > 0):
        fullEdgeName = str(fromNodeName[0]) + '->' + str(toNodeName[0]);

    if edge['fulledge'] in final_state_edges:
        unique_state_edges_order.append(edge['fulledge']);
        unique_state_edgeblocks.append(fullEdgeName);
        up = up + 1;
    else:
        unique_state_edges_order.insert(0,edge['fulledge']);
        unique_state_edgeblocks.insert(0,fullEdgeName);
        down = down + 1;

print(unique_state_edges_order);
print(unique_state_edgeblocks);
print(down); print(up);


# In[9]:


import matplotlib.pyplot as plt
import numpy as np

fig, ax = plt.subplots(figsize=(13,6))
plt.xticks(rotation=90)
plt.axhline(linewidth=1, color='darkred')
#ax.grid(True);

ax.set_ylim(-len(final_state_edges) * 10, len(final_state_edges) * 10);
ax.set_yticks(np.arange(-len(final_state_edges) * 10, len(final_state_edges) * 10, 10));
ax.set_yticklabels('');
```

```
ax.set_ylabel('Edges');

ax.set_xlim(0, len(unique_timeCreated)*10);
ax.set_xticks(np.arange(0, len(unique_timeCreated)*10, 10));
ax.set_xticklabels('');
ax.set_xlabel('Versions timeline');

x = 1;

for i in range(0,len(result_statetime)):
    yp = 1; yn= -1;
    x_range = (x, 8);
    for edgeitem in result_edges:
            if edgeitem['stateID'] == result_statetime[i]['stateID']:
                finaledge = True;
                existingedge = False;
                for j in range(i+1,len(result_statetime)):
                    state_edges = [item['fulledge'] for item in result_edges if item['
                    if edgeitem['fulledge'] not in state_edges:
                        finaledge = False;
                        break;
                for j in range(0,i):
                    state_edges = [item['fulledge'] for item in result_edges if item['
                    if edgeitem['fulledge'] in state_edges:
                        existingedge = True;
                        break;
                if finaledge:
                    if existingedge:
                        yp_range = (yp, 5);
                        yp = yp + 6;
                        ax.broken_barh([x_range],yp_range,facecolors='lightsteelblue')
                    else:
                        yp_range = (yp, 5);
                        yp = yp + 6;
                        ax.broken_barh([x_range],yp_range,facecolors='steelblue');
                else:
                    if existingedge:
                        yn_range = (yn, -5);
                        yn = yn - 6;
                        ax.broken_barh([x_range],yn_range,facecolors='sandybrown');
                    else:
```

```
                        yn_range = (yn, -5);
                        yn = yn - 6;
                        ax.broken_barh([x_range],yn_range,facecolors='darkorange');
    x = x + 10;


image_file = project_path + project_folder + '\\' + 'Volume of kept & discarded edges' + '.
fig.savefig(image_file, bbox_inches = "tight");
plt.show();


# In[10]:


import matplotlib.pyplot as plt
import numpy as np

fig, ax = plt.subplots(figsize=(13,10))
plt.xticks(rotation=90)
plt.axhline(linewidth=1, color='darkred')
ax.grid(axis='y');

ax.set_ylim(-(down*6)-3, up*6+3);
ax.set_yticks(np.arange(-(down*6)+3, up*6+3, 6));
ax.set_yticklabels(unique_state_edgeblocks);
ax.set_ylabel('Edges');

ax.set_xlim(0, len(unique_timeCreated)*10);
ax.set_xticks(np.arange(0, len(unique_timeCreated)*10, 10));
ax.set_xticklabels('');
ax.set_xlabel('Versions timeline');

x = 1;

for i in range(0,len(result_statetime)):
    x_range = (x, 8);
    for edgeitem in result_edges:
            if edgeitem['stateID'] == result_statetime[i]['stateID']:
                finaledge = True;
                existingedge = False;
                for j in range(i+1,len(result_statetime)):
```

```
                    state_edges = [item['fulledge'] for item in result_edges if item['
                    if edgeitem['fulledge'] not in state_edges:
                        finaledge = False;
                        break;
                for j in range(0,i):
                    state_edges = [item['fulledge'] for item in result_edges if item['
                    if edgeitem['fulledge'] in state_edges:
                        existingedge = True;
                        break;

               # if finaledge:
                if edgeitem['fulledge'] in final_state_edges:
                    yp_range = ((unique_state_edges_order.index(edgeitem['fulledge'])-
                    if existingedge:
                        ax.broken_barh([x_range],yp_range,facecolors='lightsteelblue')
                    else:
                        ax.broken_barh([x_range],yp_range,facecolors='steelblue');
                else:
                    yn_range = ((unique_state_edges_order.index(edgeitem['fulledge'])+
                    if existingedge:
                        ax.broken_barh([x_range],yn_range,facecolors='sandybrown');
                    else:
                        ax.broken_barh([x_range],yn_range,facecolors='darkorange');
    x = x + 10;


image_file = project_path + project_folder + '\\' + 'Specific kept & discarded edges y
fig.savefig(image_file, bbox_inches = "tight");
plt.show();

# Observe:
# the distribution of the edges that remain in the final graph
# - when do they get implemented - eg: most of them appear at the end of the project,
# or there's an even progresion of additions of edge that remain in hte final graph,
# or a lot of them get added at the beginning and persist
# the persistance of 'discarded' edges. the timeline of their appearance.
# the variety.
# how many of the edges that appear in the final graph are first discarded
# & re-introduced? eg: the toggle-> buzzer, toggle-RGB led? etc.
# what gets discarded doesn't persist long - problem-solving
```

```
# In[11]:


import matplotlib.pyplot as plt
import numpy as np

fig, ax = plt.subplots(figsize=(13,10))
plt.xticks(rotation=90)
plt.axhline(linewidth=1, color='darkred')

ax.set_ylim(-(down*6)-3, up*6+3);
ax.set_yticks(np.arange(-(down*6)+3, up*6+3, 6));
ax.set_yticklabels(unique_state_edgeblocks);
ax.set_ylabel('Edges');

ax.set_xlim(0, len(unique_timeCreated)*10);
ax.set_xticks(np.arange(0, len(unique_timeCreated)*10, 10));
ax.set_xticklabels('');
ax.set_xlabel('Versions timeline');

x = 1;

for i in range(0,len(result_statetime)):
    x_range = (x, 8);
    for edgeitem in result_edges:
            if edgeitem['stateID'] == result_statetime[i]['stateID']:
                finaledge = True;
                existingedge = False;
                for j in range(i+1,len(result_statetime)):
                    state_edges = [item['fulledge'] for item in result_edges if item['state
                    if edgeitem['fulledge'] not in state_edges:
                        finaledge = False;
                        break;
                for j in range(0,i):
                    state_edges = [item['fulledge'] for item in result_edges if item['state
                    if edgeitem['fulledge'] in state_edges:
                        existingedge = True;
                        break;

               # if finaledge:
```

```
                if edgeitem['fulledge'] in final_state_edges:
                    yp_range = ((unique_state_edges_order.index(edgeitem['fulledge'])-
                    if existingedge:
                        ax.broken_barh([x_range],yp_range,facecolors='lightsteelblue')
                    else:
                        ax.broken_barh([x_range],yp_range,facecolors='steelblue');
                else:
                    yn_range = ((unique_state_edges_order.index(edgeitem['fulledge'])+
                    if existingedge:
                        ax.broken_barh([x_range],yn_range,facecolors='sandybrown');
                    else:
                        ax.broken_barh([x_range],yn_range,facecolors='darkorange');
    x = x + 10;


image_file = project_path + project_folder + '\\' + 'Specific kept & discarded edges'
fig.savefig(image_file, bbox_inches = "tight");
plt.show();

# Observe:
# the distribution of the edges that remain in the final graph
# when do they get implemented - eg: most of them appear at the end of the project,
# or there's an even progresion of additions of edge that remain in hte final graph,
# or a lot of them get added at the beginning and persist
# the persistance of 'discarded' edges. the timeline of their appearance.
# the variety.
# how many of the edges that appear in the final graph are first discarded
# & re-introduced? eg: the toggle-> buzzer, toggle-RGB led? etc.
# what gets discarded doesn't persist long - problem-solving


# In[12]:


import matplotlib.pyplot as plt
import numpy as np
import matplotlib.pyplot as plt
import numpy as np

fig, ax = plt.subplots(figsize=(13,10))
plt.xticks(rotation=90)
```

```
plt.axhline(linewidth=1, color='darkred')
ax.grid(axis='y');

ax.set_ylim(-(down*6)-3, up*6+3);
ax.set_yticks(np.arange(-(down*6)+3, up*6+3, 6));
ax.set_yticklabels(unique_state_edgeblocks);
ax.set_ylabel('Edges');

ax.set_xlim(0, len(unique_timeCreated)*10);
ax.set_xticks(np.arange(0, len(unique_timeCreated)*10, 10));
ax.set_xticklabels('');
ax.set_xlabel('Versions timeline');

x = 1;

for i in range(0,len(result_statetime)):
    x_range = (x, 8);
    for edgeitem in result_edges:
            if edgeitem['stateID'] == result_statetime[i]['stateID']:
                finaledge = True;
                existingedge = False;
                valid = [item['valid'] for item in result_paths if (item['stateID'] == edge
                if len(valid) == 0: valid = [0];
                for j in range(i+1,len(result_statetime)):
                    state_edges = [item['fulledge'] for item in result_edges if item['state
                    if edgeitem['fulledge'] not in state_edges:
                        finaledge = False;
                        break;
                for j in range(0,i):
                    state_edges = [item['fulledge'] for item in result_edges if item['state
                    if edgeitem['fulledge'] in state_edges:
                        existingedge = True;
                        break;

               # if finaledge:
                if edgeitem['fulledge'] in final_state_edges:
                    yp_range = ((unique_state_edges_order.index(edgeitem['fulledge'])-down)
                    if existingedge:
                        if valid[0] == 1:
                            ax.broken_barh([x_range],yp_range,facecolors='darkseagreen');
                        else:
```

```
                            ax.broken_barh([x_range],yp_range,facecolors='grey');
                    else:
                        if valid[0] == 1:
                            ax.broken_barh([x_range],yp_range,facecolors='green');
                        else:
                            ax.broken_barh([x_range],yp_range,facecolors='black');
                else:
                    yn_range = ((unique_state_edges_order.index(edgeitem['fulledge'])+
                    if existingedge:
                        if valid[0] == 1:
                            ax.broken_barh([x_range],yn_range,facecolors='darkseagreen
                        else:
                            ax.broken_barh([x_range],yn_range,facecolors='grey');
                    else:
                        if valid[0] == 1:
                            ax.broken_barh([x_range],yn_range,facecolors='green');
                        else:
                            ax.broken_barh([x_range],yn_range,facecolors='black');
    x = x + 10;


image_file = project_path + project_folder + '\\' + 'Validity of kept & discarded edge
fig.savefig(image_file, bbox_inches = "tight");
plt.show();

# Observe:
# the distribution of the edges that remain in the final graph
# when do they get implemented - eg: most of them appear at the end of the project,
# or there's an even progresion of additions of edge that remain in the final graph,
# or a lot of them get added at the beginning and persist
# the persistance of 'discarded' edges. the timeline of their appearance.
# the variety.
# how many of the edges that appear in the final graph are first discarded
# & re-introduced? eg: the toggle-> buzzer, toggle-RGB led? etc.
# what gets discarded doesn't persist long - problem-solving


# In[13]:


import matplotlib.pyplot as plt
```

```
import numpy as np
import matplotlib.pyplot as plt
import numpy as np

fig, ax = plt.subplots(figsize=(13,10))
plt.xticks(rotation=90)
plt.axhline(linewidth=1, color='darkred')

ax.set_ylim(-(down*6)-3, up*6+3);
ax.set_yticks(np.arange(-(down*6)+3, up*6+3, 6));
ax.set_yticklabels(unique_state_edgeblocks);
ax.set_ylabel('Edges');

ax.set_xlim(0, len(unique_timeCreated)*10);
ax.set_xticks(np.arange(0, len(unique_timeCreated)*10, 10));
ax.set_xticklabels('');
ax.set_xlabel('Versions timeline');

x = 1;

for i in range(0,len(result_statetime)):
    x_range = (x, 8);
    for edgeitem in result_edges:
            if edgeitem['stateID'] == result_statetime[i]['stateID']:
                finaledge = True;
                existingedge = False;
                valid = [item['valid'] for item in result_paths if (item['stateID'] == edge
                if len(valid) == 0: valid = [0];
                for j in range(i+1,len(result_statetime)):
                    state_edges = [item['fulledge'] for item in result_edges if item['state
                    if edgeitem['fulledge'] not in state_edges:
                        finaledge = False;
                        break;
                for j in range(0,i):
                    state_edges = [item['fulledge'] for item in result_edges if item['state
                    if edgeitem['fulledge'] in state_edges:
                        existingedge = True;
                        break;

               # if finaledge:
                if edgeitem['fulledge'] in final_state_edges:
```

```
                    yp_range = ((unique_state_edges_order.index(edgeitem['fulledge'])-
                    if existingedge:
                        if valid[0] == 1:
                            ax.broken_barh([x_range],yp_range,facecolors='darkseagreen
                        else:
                            ax.broken_barh([x_range],yp_range,facecolors='grey');
                    else:
                        if valid[0] == 1:
                            ax.broken_barh([x_range],yp_range,facecolors='green');
                        else:
                            ax.broken_barh([x_range],yp_range,facecolors='black');
                else:
                    yn_range = ((unique_state_edges_order.index(edgeitem['fulledge'])+
                    if existingedge:
                        if valid[0] == 1:
                            ax.broken_barh([x_range],yn_range,facecolors='darkseagreen
                        else:
                            ax.broken_barh([x_range],yn_range,facecolors='grey');
                    else:
                        if valid[0] == 1:
                            ax.broken_barh([x_range],yn_range,facecolors='green');
                        else:
                            ax.broken_barh([x_range],yn_range,facecolors='black');
    x = x + 10;


image_file = project_path + project_folder + '\\' + 'Validity of kept & discarded edge
fig.savefig(image_file, bbox_inches = "tight");
plt.show();

# Observe:
# the distribution of the edges that remain in the final graph
# when do they get implemented - eg: most of them appear at the end
# of the project, or there's an even progresion of additions of edge
# that remain in hte final graph, or a lot of them get added at the beginning and pers
# the persistance of 'discarded' edges.
# the timeline of their appearance. the variety.
# how many of the edges that appear in the final graph are first discarded
# & re-introduced? eg: the toggle-> buzzer, toggle-RGB led? etc.
# what gets discarded doesn't persist long - problem-solving
```

```
Blocks across Contexts


\textbf{#!/usr/bin/env python
# coding: utf-8

# In[1]:


import pymysql.cursors
connection = pymysql.connect(host='localhost',
                             user='user',
                             password='password',
                             db='samlogs',
                             charset='utf8mb4',
                             cursorclass=pymysql.cursors.DictCursor,
                             autocommit=True)

#try:
with connection.cursor() as cursor:
    print(cursor.execute("SELECT distinct invalid_reason FROM samlogs.directedgraphs"))

project_path = "project_path";

project_folder = "project_folder";
projectID = ('projectID',);

#one project
parameters = (projectID,);

#2 or more projects
#projectID2 = ('7projectID2',);
#parameters = (projectID,projectID2,);


# In[2]:


with connection.cursor() as cursor:
    #one project
```

```
    cursor.execute("SELECT DISTINCT ID,timeCreated,path_label,valid, _
                  invalid_reason,behaviour,progressing_path_ID _
                  FROM samlogs.directedgraphs JOIN samlogs.nodes _
                  ON directedgraphs.stateID = nodes.stateID _
                  WHERE directedgraphs.projectID = %s", parameters);

    #2 or more projects
    #cursor.execute("SELECT DISTINCT ID,timeCreated,path_label,valid,invalid_reason,be

    result = cursor.fetchall();
    print(len(result))


# In[3]:


pathLabel = [ item['path_label'] for item in result ]
print (len(pathLabel))

unique_directed_paths = set(pathLabel);
print(unique_directed_paths);


# In[4]:


inputs = ['Button', 'Potentiometer', 'Tilt', 'Keyboard', 'LDR',
          'TweetIn', 'RotaryPot', 'Pressure', 'IRSensor',
          'Temperature', 'TimeTrigger', 'LightSensor',
          'Proximity', 'CarController',
          'TriggerKey', 'TriggerMouse', 'ProcessingIn', 'MidiIn',
          'Accelerometer', 'GPS', 'IPhone', 'SensorActorProto',
          'Joystick'];

outputs = ['RGBLED', 'DCMotor', 'ServoMotor', 'Buzzer', 'Camera',
           'Player', 'TweetOut', 'Vibrator', 'Fan', 'TriggerText',
          'iftttOut', 'FacebookOut', 'DigitalOut', 'MidiOut',
           'ProcessingOut', 'HueLight', 'Servo', 'Say', 'Drone', 'Nest',
           'TwoMotors', 'Sonos', 'Tesco', 'AnyIO', 'LeapMotionSwipe',
           'LeapMotionPosition', 'LeapMotionHand', 'Sphero',
           'LeapMotionCircle', 'MqttOut'];
```

```
connections =['CodeModule', 'Toggle', 'Counter', 'NumberValue',
              'CycleColours', 'Comparator', 'Hold', 'Delay', 'Text',
              'Filter', 'Inverse', 'LogicAnd', 'Sequencer', 'Interval',
              'OnOff', 'Log', 'MorseCode', 'LogicOr', 'Colour',
              'CycleBrightness', 'Direction', 'SwitchDirection',
              'LogicNor', 'Relay', 'CycleFrequency', 'LogicXor', 'Note',
              'LogicNand', 'CycleVolume', 'Threshold', 'Scale', 'Switch',
              'Content', 'Map', 'CloudWifi', 'MotorMovement', 'Cloud',
              'MidiMessage', 'Ultrasonic', 'DotMatrix', 'Serial',
              'MIC', 'Inspect', 'StateMachine', 'IMU', 'AmplifyNum'];

print(inputs); print(outputs); print(connections);


# In[5]:


blocks = ['CodeModule'];


# In[6]:


paths_with_blocks = [];

for path in unique_directed_paths:
    all_blocks = True;
    for block in blocks:
        # as soon as you find a block from the ones we're interested
        #in that's not in the path, move on to next path
        # we're only keeping the paths that contain
        #all the blocks we're interested in
        if block not in path:
            all_blocks = False;
            break;
    if all_blocks == True:
        paths_with_blocks.append(path);

print(paths_with_blocks);
```

```
lowest_blocks = [];
highest_blocks = [];
max_length = 0;
for i in range(0,len(blocks)): lowest_blocks.append(9999);
for i in range(0,len(blocks)): highest_blocks.append(0);

for i in range(0,len(paths_with_blocks)):
    path_blocks = paths_with_blocks[i][2:].split('->');
    if len(path_blocks) > max_length:
            max_length = len(path_blocks);
    for j in range (0, len(blocks)):
        if path_blocks.index(blocks[j]) < lowest_blocks[j]:
            lowest_blocks[j] = path_blocks.index(blocks[j]);
        if path_blocks.index(blocks[j]) > highest_blocks[j]:
            highest_blocks[j] = path_blocks.index(blocks[j]);

print(lowest_blocks); print(highest_blocks); print(max_length);


# In[7]:


nodes = {};
node_properties = {}; # 'label', 'colour', 'pos' = (x,y)
edges = {};
# 'weight' - set as edge width
print(blocks)
for i in range (0, len(paths_with_blocks)):
    path_blocks = paths_with_blocks[i][2:].split('->');

    weight = 0;
    for item in result:
        if item['path_label'] == paths_with_blocks[i]:
            weight = weight + 0.25;

    for j in range(0,len(path_blocks)):
        node_properties = {};
        node = str(path_blocks[j]) + str(i);
        node_properties['label'] = path_blocks[j];
        if path_blocks[j] in blocks:
            node_properties['colour'] = '#dc143c';
```

```
        elif path_blocks[j] in inputs:
            node_properties['colour'] = '#F0D9D9';
        elif path_blocks[j] in outputs:
            node_properties['colour'] = '#FAEBC5';
        elif path_blocks[j] in connections:
            node_properties['colour'] = '#EDEDF0';

        pos_x = (i+1)*10;
        pos_y = (j+1)*10;
        pos = (pos_x,pos_y);
        node_properties['pos'] = pos;

        nodes[node] = node_properties;

        if j > 0:
            previous_node = str(path_blocks[j-1]) + str(i);
            edge = (previous_node,node);
            if edge in edges.keys():
                edges[edge]['weight'] = weight;
            else:
                edges.update({edge:{'weight': weight}});


print(nodes); print(edges);




# In[8]:



import networkx as nx
import matplotlib.pyplot as plt

plt.figure(figsize=(20,12))

G = nx.DiGraph();
G.add_nodes_from(nodes);
nx.set_node_attributes(G, nodes);
G.add_edges_from(edges);
nx.set_edge_attributes(G, edges);
```

```
nodecolordict = nx.get_node_attributes(G,'colour');
nodecolorlist = [];
for key, value in nodecolordict.items():
    nodecolorlist.append(value);

labeldict = nx.get_node_attributes(G,'label');
pos = nx.get_node_attributes(G,'pos');

nx.draw_networkx_nodes(G, pos, node_size=6500, node_color=nodecolorlist);
nx.draw_networkx_labels(G, pos, labels=labeldict, with_labels=True)
nx.draw_networkx_edges(G, pos, width=list(nx.get_edge_attributes(G,'weight').values())

blocknames = ''
for block in blocks:
    blocknames = blocknames + str(block) + ' ';

image_file = project_path + project_folder + '\\' + 'Cross-context usage of ' + blockn
plt.savefig(image_file, bbox_inches = "tight");
plt.show()

#!/usr/bin/env python
# coding: utf-8

# In[9]:



import pymysql.cursors
connection = pymysql.connect(host='localhost',
                                     user='user',
                                     password='password',
                                     db='samlogs',
                                     charset='utf8mb4',
                                     cursorclass=pymysql.cursors.DictCursor,
                                     autocommit=True)

#try:
with connection.cursor() as cursor:
    print(cursor.execute("SELECT distinct invalid_reason FROM samlogs.directedgraphs")

project_path = "project_path";
```

```
project_folder = "project_folder";
projectID = ('projectID',);

#one project
parameters = (projectID,);

#2 or more projects
#projectID2 = ('7projectID2',);
#parameters = (projectID,projectID2,);


# In[10]:


with connection.cursor() as cursor:
    #one project
    cursor.execute("SELECT DISTINCT ID,timeCreated,path_label,valid, _
                   invalid_reason,behaviour,progressing_path_ID _
                   FROM samlogs.directedgraphs JOIN samlogs.nodes _
                   ON directedgraphs.stateID = nodes.stateID _
                   WHERE directedgraphs.projectID = %s", parameters);

    #2 or more projects
    #cursor.execute("SELECT DISTINCT ID,timeCreated,path_label,valid,invalid_reason,behavio

    result = cursor.fetchall();
    print(len(result))


# In[11]:


pathLabel = [ item['path_label'] for item in result ]
print (len(pathLabel))

unique_directed_paths = set(pathLabel);
print(unique_directed_paths);


# In[12]:
```

```
inputs = ['Button', 'Potentiometer', 'Tilt', 'Keyboard', 'LDR',
          'TweetIn', 'RotaryPot', 'Pressure', 'IRSensor',
          'Temperature', 'TimeTrigger', 'LightSensor',
          'Proximity', 'CarController',
          'TriggerKey', 'TriggerMouse', 'ProcessingIn', 'MidiIn',
          'Accelerometer', 'GPS', 'IPhone', 'SensorActorProto',
          'Joystick'];

outputs = ['RGBLED', 'DCMotor', 'ServoMotor', 'Buzzer', 'Camera',
           'Player', 'TweetOut', 'Vibrator', 'Fan', 'TriggerText',
          'iftttOut', 'FacebookOut', 'DigitalOut', 'MidiOut',
           'ProcessingOut', 'HueLight', 'Servo', 'Say', 'Drone', 'Nest',
           'TwoMotors', 'Sonos', 'Tesco', 'AnyIO', 'LeapMotionSwipe',
           'LeapMotionPosition', 'LeapMotionHand', 'Sphero',
           'LeapMotionCircle', 'MqttOut'];

connections =['CodeModule', 'Toggle', 'Counter', 'NumberValue',
              'CycleColours', 'Comparator', 'Hold', 'Delay', 'Text',
              'Filter', 'Inverse', 'LogicAnd', 'Sequencer', 'Interval',
              'OnOff', 'Log', 'MorseCode', 'LogicOr', 'Colour',
              'CycleBrightness', 'Direction', 'SwitchDirection',
              'LogicNor', 'Relay', 'CycleFrequency', 'LogicXor', 'Note',
              'LogicNand', 'CycleVolume', 'Threshold', 'Scale', 'Switch',
              'Content', 'Map', 'CloudWifi', 'MotorMovement', 'Cloud',
              'MidiMessage', 'Ultrasonic', 'DotMatrix', 'Serial',
              'MIC', 'Inspect', 'StateMachine', 'IMU', 'AmplifyNum'];

print(inputs); print(outputs); print(connections);


# In[13]:


blocks = ['CodeModule'];


# In[14]:


paths_with_blocks = [];
```

```
for path in unique_directed_paths:
    all_blocks = True;
    for block in blocks:
        # as soon as you find a block from the ones we're interested
        #in that's not in the path, move on to next path
        # we're only keeping the paths that contain
        #all the blocks we're interested in
        if block not in path:
            all_blocks = False;
            break;
    if all_blocks == True:
        paths_with_blocks.append(path);

print(paths_with_blocks);

lowest_blocks = [];
highest_blocks = [];
max_length = 0;
for i in range(0,len(blocks)): lowest_blocks.append(9999);
for i in range(0,len(blocks)): highest_blocks.append(0);

for i in range(0,len(paths_with_blocks)):
    path_blocks = paths_with_blocks[i][2:].split('->');
    if len(path_blocks) > max_length:
            max_length = len(path_blocks);
    for j in range (0, len(blocks)):
        if path_blocks.index(blocks[j]) < lowest_blocks[j]:
            lowest_blocks[j] = path_blocks.index(blocks[j]);
        if path_blocks.index(blocks[j]) > highest_blocks[j]:
            highest_blocks[j] = path_blocks.index(blocks[j]);

print(lowest_blocks); print(highest_blocks); print(max_length);


# In[15]:


nodes = {};
node_properties = {}; # 'label', 'colour', 'pos' = (x,y)
edges = {};
```

```
# 'weight' - set as edge width
print(blocks)
for i in range (0, len(paths_with_blocks)):
    path_blocks = paths_with_blocks[i][2:].split('->');

    weight = 0;
    for item in result:
        if item['path_label'] == paths_with_blocks[i]:
            weight = weight + 0.25;

    for j in range(0,len(path_blocks)):
        node_properties = {};
        node = str(path_blocks[j]) + str(i);
        node_properties['label'] = path_blocks[j];
        if path_blocks[j] in blocks:
            node_properties['colour'] = '#dc143c';
        elif path_blocks[j] in inputs:
            node_properties['colour'] = '#F0D9D9';
        elif path_blocks[j] in outputs:
            node_properties['colour'] = '#FAEBC5';
        elif path_blocks[j] in connections:
            node_properties['colour'] = '#EDEDF0';

        pos_x = (i+1)*10;
        pos_y = (j+1)*10;
        pos = (pos_x,pos_y);
        node_properties['pos'] = pos;

        nodes[node] = node_properties;

        if j > 0:
            previous_node = str(path_blocks[j-1]) + str(i);
            edge = (previous_node,node);
            if edge in edges.keys():
                edges[edge]['weight'] = weight;
            else:
                edges.update({edge:{'weight': weight}});


print(nodes); print(edges);
```

```
# In[16]:


import networkx as nx
import matplotlib.pyplot as plt

plt.figure(figsize=(20,12))

G = nx.DiGraph();
G.add_nodes_from(nodes);
nx.set_node_attributes(G, nodes);
G.add_edges_from(edges);
nx.set_edge_attributes(G, edges);

nodecolordict = nx.get_node_attributes(G,'colour');
nodecolorlist = [];
for key, value in nodecolordict.items():
    nodecolorlist.append(value);

labeldict = nx.get_node_attributes(G,'label');
pos = nx.get_node_attributes(G,'pos');

nx.draw_networkx_nodes(G, pos, node_size=6500, node_color=nodecolorlist);
nx.draw_networkx_labels(G, pos, labels=labeldict, with_labels=True)
nx.draw_networkx_edges(G, pos, width=list(nx.get_edge_attributes(G,'weight').values()));

blocknames = ''
for block in blocks:
    blocknames = blocknames + str(block) + ' ';

image_file = project_path + project_folder + '\\' + 'Cross-context usage of ' + blocknames
plt.savefig(image_file, bbox_inches = "tight");
plt.show()

}


Distinct Approaches
```

```
#!/usr/bin/env python
# coding: utf-8

# In[1]:



import pymysql.cursors
connection = pymysql.connect(host='localhost',
                                     user='user',
                                     password='password',
                                     db='samlogs',
                                     charset='utf8mb4',
                                     cursorclass=pymysql.cursors.DictCursor,
                                     autocommit=True)

#try:
with connection.cursor() as cursor:
    print(cursor.execute("SELECT distinct invalid_reason FROM samlogs.directedgraphs")

project_path = "project_path";

project_folder = "project_folder";
projectID = ('projectID',);
behaviour = ('question',);

#one project
parameters = (projectID,behaviour,);

#2 or more projects
#projectID2 = ('projectID2',);
#parameters = (projectID,projectID2,behaviour,);


# In[2]:



with connection.cursor() as cursor:
    #one project
    cursor.execute("SELECT * FROM samlogs.states_ba _
                   WHERE projectID = %s AND behaviour = %s", parameters);
```

```
    #2 or more projects
    #cursor.execute("SELECT * FROM samlogs.states_ba _
                WHERE (projectID = %s OR projectID = %s) AND behaviour = %s", parameters

    result = cursor.fetchall();
    print(len(result))


# In[3]:


timeCreated = [ item['timeCreated'] for item in result ]
#x = states equally spaced out / spaced out
#proportionally by the time lapsed between them
print (len(timeCreated));


# In[4]:


valid = [ item['valid'] for item in result ]
print (len(valid))


# In[5]:


with connection.cursor() as cursor:
    #one project
    cursor.execute("SELECT DISTINCT approach_identical _
                FROM samlogs.states_ba WHERE projectID = %s _
                AND behaviour = %s", parameters);

    #2 or more projects
    #cursor.execute("SELECT DISTINCT approach_identical _
                FROM samlogs.states_ba WHERE (projectID = %s OR projectID = %s) _
                AND behaviour = %s", parameters);

    approach_identical = cursor.fetchall();
```

```
unique_approaches = [ item['approach_identical'] for item in approach_identical ]
print(unique_approaches)


# In[6]:


approaches = [ item['approach'] for item in result ]
print(approaches)


# In[7]:


import matplotlib.pyplot as plt
import numpy as np

fig, ax = plt.subplots(figsize=(50,10))
plt.xticks(rotation=90)
ax.yaxis.grid(linestyle='--')

ax.set_ylim(0, len(unique_approaches)*10+10);
ax.set_yticks(np.arange(10, len(unique_approaches)*10+10, 10));
ax.set_yticklabels(unique_approaches, fontsize=30);
ax.set_ylabel('Unique Approaches', fontsize=30);

ax.set_xlim(10, len(timeCreated)*10+10);
ax.set_xticks(np.arange(10, len(timeCreated)*10+10, 10));
ax.set_xticklabels('');
ax.set_xlabel('Approaches Timeline', fontsize=30);

i=5;

for approach in unique_approaches:
    markings_valid = [];
    markings_invalid = [];
    for item in result:
        if approach == item['approach_identical']:
            if item['valid'] == 1:
                markings_valid.append(timeCreated.index(item['timeCreated']) * 10);
            else:
```

```
                markings_invalid.append(timeCreated.index(item['timeCreated']) * 10);

    xranges_valid = [];
    for item in markings_valid:
        list = (item,10);
        xranges_valid.append(list);

    x_ranges_invalid = [];
    for item in markings_invalid:
        list = (item,10);
        x_ranges_invalid.append(list);

    yrange = (i,9);
    ax.broken_barh(xranges_valid,yrange,facecolors='#d0f0c0');
    #ax.broken_barh(x_ranges_invalid,yrange,facecolors='red');
    #- fix/remove the red bits!!
    ax.broken_barh(x_ranges_invalid,yrange,facecolors='#a8a8a8');

    i = i+10;

image_file = project_path + project_folder + '\\' + 'Behaviours and Approaches over Time pe
fig.savefig(image_file, bbox_inches = "tight");
plt.show();
```

Appendix E

Student Data Ethics Application Details

Institute of Education

Ethics Application Form: Student Research

Anyone conducting research under the auspices of the Institute (staff, students or visitors) where the research involves human participants or the use of data collected from human participants, is required to gain ethical approval before starting. This includes preliminary and pilot studies. Please answer all relevant questions in terms that can be understood by a lay person and note that your form may be returned if incomplete.

For further support and guidance please see accompanying guidelines and the Ethics Review Procedures for Student Research http://www.ucl.ac.uk/srs/research-ethics-committee/ioe or contact your supervisor or IOE.researchethics@ucl.ac.uk.

Before completing this form you will need to discuss your proposal fully with your supervisor(s). Please attach all supporting documents and letters.

For all Psychology students, this form should be completed with reference to the British Psychological Society (BPS) Code of Human Research Ethics and Code of Ethics and Conduct.

Section 1 Project details					
a.	Project title	Using learning analytics to expose and better support the practice-based learning and teaching process in STEAM education			
b.	Student name	Veronica Cucuiat			
c.	Supervisor/Personal Tutor	Rose Luckin			
d.	Department	Institute of Education			
e.	Course category (Tick one)	PhD/MPhil	☒	EdD	☐
		MRes	☐	DEdPsy	☐
		MTeach	☐	MA/MSc	☐
		ITE	☐		
		Diploma (state which)	☐		
		Other (state which)	☐		
f.	Course/module title				
g.	**If applicable,** state who the funder is and if funding has been confirmed.	Bloomsbury Colleges PhD Studentship 2016			
h.	Intended research start date	26/05/2017			
i.	Intended research end date	01/10/2019			
j.	Country fieldwork will be conducted in	UK			

	If research to be conducted abroad please ensure travel insurance is obtained through UCL *http://www.ucl.ac.uk/finance/insurance/travel*	

k.	Has this project been considered by another (external) Research Ethics Committee?	
	Yes ☐	External Committee Name:
	No ☒ ⇨ *go to Section 2*	Date of Approval:

If yes:

- Submit a copy of the approval letter with this application.
- Proceed to Section 10 Attachments**.**

Note: Ensure that you check the guidelines carefully as research with some participants will require ethical approval from a different ethics committee such as the National Research Ethics Service (NRES) or Social Care Research Ethics Committee (SCREC). In addition, if your research is based in another institution then you may be required to apply to their research ethics committee.

Section 2 Project summary

Research methods (tick all that apply)

Please attach questionnaires, visual methods and schedules for interviews (even in draft form).

- ☒ Interviews
- ☐ Focus groups
- ☒ Questionnaires
- ☐ Action research
- ☒ Observation
- ☒ Literature review
- ☐ Controlled trial/other intervention study
- ☐ Use of personal records
- ☐ Systematic review ⇨ ***if only method used go to Section 5.***
- ☐ Secondary data analysis ⇨ ***if secondary analysis used go to Section 6.***
- ☒ Advisory/consultation/collaborative groups
- ☐ Other, give details:

Please provide an overview of your research. This should include some or all of the following: purpose of the research, aims, main research questions, research design, participants, sampling, your method of data collection (e.g., observations, interviews, questionnaires, etc.) and kind of questions that will be asked, reporting and dissemination (typically 300-500 words).

Research project summary

Research in educational environments paves the way to a better understanding of the learning process and the teaching methods which support it. Part of my research within the University College London Institute of Education I analyse data from learning environments to expose and better support the practice-based teaching and learning process in STEM education.

I want to find innovative ways of collecting, analysing and interpreting data in the most helpful, ethical and efficacious ways possible within both physical and digital learning environments. As technology proliferates its way into the classrooms, it is our duty as researchers to stay on top of the innovation curve in terms of the role and impact these technologies end up having.

What does that mean?

Through observational videos, audio recordings and sensory data from the environment I hope to better understand the project-based learning methods which your school is heavily applying. As a researcher, I fully endorse project-based learning as a pedagogical methodology and through data, I seek to explore what makes it an effective learning process and understand how its benefits can be maximised. After collecting my research data, I intend to apply manual analysis as well as machine learning algorithms to dissect the project-based learning process, as well as explore how to best interpret and use this data to support it.

More specifically, I would like to observe and record, for the period of one semester, the children at two different schools undertaking a project based learning methodology class. From this, I am hoping to use the different data streams - video, audio and sensory, as well as questionnaires and interviews to explore the following ideas:

- **Multi-modal data analysis** - How do different data streams collected from different devices, recording different things from the same environment at the same time correlate to paint a complete picture of the learning process?
- **Project based learning guidelines** - How can the data be used to break down the project-based learning process? What insights can data provide which helps us understand the principles which underpin project based learning? How can these form the base of a recommended structure for project based learning activities strongly correlated to its perceived benefits?
- **Study project based learning "in the wild"** - many of the current project based learning research is done from controlled environments where researchers mold the experience in order to fit their research questions. Whilst these methods are perfectly valid, a secondary approach is to study these concepts 'in the wild' - where they happen in real life with minimum tampering of the process which happens naturally.
- **SAM Labs across the curriculum** - As well as within the digital computing classes, the SAM Labs blocks represent a means of integrating technology in a ubiquitous manner across all subjects in the curriculum. Given the extended potential technologies offer for studying any concept as well as the increasing reliance on technologies to aid human work in any field, the impact of ubiquitous computational tools in the context of learning and its evolution needs to be explored and understood.
- **Individuality** - How do individuals behave differently from one another in the context of project based learning? As well as…. How differently do individuals behave from one another in the context of project based learning? What does adaptivity mean in the context of project based learning and how can data contribute to supporting project based learning adaptive environments?

The recorded classes will be preceded by purely observatory sessions, in both schools, where the details of where the video, audio and sensory data collection devices will be placed and the way in which they will be managed will be scoped out, discussed and agreed with the teachers. In addition, if any surveys, questionnaires or other manual data is to be collected, it will be scoped out during the initial observatory sessions and will be agreed with the teachers in advance of the recorded classes.

Section 3 Participants

Please answer the following questions giving full details where necessary. Text boxes will expand for your responses.

a.	Will your research involve human participants?	Yes ☒	No ☐ ⇨ *go to Section 4*

b. Who are the participants (i.e. what sorts of people will be involved)? Tick all that apply.

Children and Teachers

☐ Early years/pre-school	☐ Unknown – specify below
☒ Ages 5-11	☒ Adults *please specify below*
☒ Ages 12-16	☐ Other – specify below
☐ Young people aged 17-18	Teachers

NB: Ensure that you check the **guidelines** (Section 1) carefully as research with some participants will require ethical approval from a different ethics committee such as the National Research Ethics Service (NRES).

c. If participants are under the responsibility of others (such as parents, teachers or medical staff) how do you intend to obtain permission to approach the participants to take part in the study?

(Please attach approach letters or details of permission procedures – see Section 9 Attachments.)

	The tracking devices setup will be agreed and organised with specific school teachers and headmasters of the two schools. Parents will be asked to agree to their child participating in the workshop via informed consent forms. Children will be presented with assent forms at the beginning of each workshop to ensure they are aware of their options and free willing to participate in the workshop.
d.	How will participants be recruited (identified and approached)? The two schools have been recruited based on their application of project based learning methodology during some of their classes and their willingness to participate in this research. The specific classes which will be recorded will be agreed with the teachers and all students participating in the class and whose parents / guardians have given their consent will be involved in the research.
e.	Describe the process you will use to inform participants about what you are doing. The children will be briefed at the beginning of the semester on their voluntary participation, that they are free to opt-out of the recordings entirely, or raise any concerns at any point throughout the recordings. The children will also be told exactly what data will be recorded – video and audio recordings of the classes, questionnaires, interviews and informal questions throughout the day. An explanation of how exactly the data will be used – in a project report or article, anonymised, in the form of quotes, blurred pictures or video clips, or quantitative data totalled up, analysed and interpreted. This information will be outlined in an assent form which the children will be asked to sign at the beginning of the semester. The children will be encouraged to speak to any teacher or myself and voice any concerns or problems they might have with the recordings.
f.	How will you obtain the consent of participants? Will this be written? How will it be made clear to participants that they may withdraw consent to participate at any time? *See the guidelines for information on opt-in and opt-out procedures. Please note that the method of consent should be appropriate to the research and fully explained.* Written consent forms will be signed by the children's parents. Information sheets will be provided to them to explain the purpose and procedure of the data collection and the nature of children's participation. Children and parents will be informed that the they can withdraw their consent up until the point of a report hand-in / article publication. Written assent forms will be signed by children before the start of the semester where their options to opt-out will be made clear.
g.	**Studies involving questionnaires:** Will participants be given the option of omitting questions they do not wish to answer? Yes ☒ No ☐
	If **NO** please explain why below and ensure that you cover any ethical issues arising from this in section 8.
h.	**Studies involving observation:** Confirm whether participants will be asked for their informed consent to be observed. Yes ☒ No ☐
	If **NO** read the guidelines (Ethical Issues section) and explain why below and ensure that you cover any ethical issues arising from this in section 8.

i.	Might participants experience anxiety, discomfort or embarrassment as a result of your study? Yes ☐ No ☒
	If **yes** what steps will you take to explain and minimise this? If **not**, explain how you can be sure that no discomfort or embarrassment will arise? The recordings will be done at the children's school with their teachers present. The devices will be embedded in the environment as much as possible. Any signs of discomfort will be taken seriously and enquired. More details in section 8 of this application form.
j.	Will your project involve deliberately misleading participants (deception) in any way? Yes ☐ No ☒
	If **YES** please provide further details below and ensure that you cover any ethical issues arising from this in section 8.
k.	Will you debrief participants at the end of their participation (i.e. give them a brief explanation of the study)? Yes ☒ No ☐
	If **NO** please explain why below and ensure that you cover any ethical issues arising from this in section 8.
l.	Will participants be given information about the findings of your study? (This could be a brief summary of your findings in general; it is not the same as an individual debriefing.) Yes ☒ No ☐
	If **no**, why not?

Section 4 Security-sensitive material
Only complete if applicable

Security sensitive research includes: commissioned by the military; commissioned under an EU security call; involves the acquisition of security clearances; concerns terrorist or extreme groups.

a.	Will your project consider or encounter security-sensitive material?	Yes ☐ *	No ☐
b.	Will you be visiting websites associated with extreme or terrorist organisations?	Yes ☐ *	No ☐
c.	Will you be storing or transmitting any materials that could be interpreted as promoting or endorsing terrorist acts?	Yes ☐ *	No ☐

* *Give further details in* ***Section 8 Ethical Issues***

Section 5 Systematic review of research
Only complete if applicable

a.	Will you be collecting any new data from participants?	Yes ☒ *	No ☐

b.	Will you be analysing any secondary data?	Yes ☐ *	No ☒

* *Give further details in* ***Section 8 Ethical Issues***

If your methods do not involve engagement with participants (e.g. systematic review, literature review) ***and*** *if you have answered* ***No*** *to both questions, please go to* ***Section 10 Attachments.***

Section 6 Secondary data analysis Complete for all secondary analysis

a.	Name of dataset/s		
b.	Owner of dataset/s		
c.	Are the data in the public domain?	Yes ☐ No ☐ ***If no,*** *do you have the owner's permission/license?* Yes ☐ No* ☐	
d.	Are the data anonymised?	Yes ☐ No ☐	
		Do you plan to anonymise the data?	Yes ☐ No* ☐
		Do you plan to use individual level data?	Yes* ☐ No ☐
		Will you be linking data to individuals?	Yes* ☐ No ☐
e.	Are the data sensitive ([DPA 1998 definition](#))?	Yes* ☐	No ☐
f.	Will you be conducting analysis within the remit it was originally collected for?	Yes ☐	No* ☐
g.	**If no,** was consent gained from participants for subsequent/future analysis?	Yes ☐	No* ☐
h.	**If no,** was data collected prior to ethics approval process?	Yes ☐	No* ☐

* *Give further details in* ***Section 8 Ethical Issues***

If secondary analysis is only method used ***and*** *no answers with asterisks are ticked, go to* ***Section 9 Attachments.***

Section 7 Data Storage and Security

Please ensure that you include all hard and electronic data when completing this section.

a.	Confirm that all personal data will be stored and processed in compliance with the Data Protection Act 1998 (DPA 1998). *(See the Guidelines and the Institute's Data Protection & Records Management Policy for more detail.)*		Yes ☒
b.	Will personal data be processed or be sent outside the European Economic Area?	Yes ☐ *	No ☒

* **If yes,** please confirm that there are adequate levels of protections in compliance with the DPA 1998 and state what these arrangements are below.

c.	Who will have access to the data and personal information, including advisory/consultation groups and during transcription? Myself, my project supervisor, the teachers in the school and the children used for the research workshop.

During the research	
d.	Where will the data be stored? Personal computer and password-protected hard drive storage devices.
e.	Will mobile devices such as USB storage and laptops be used? Yes ☒ * No ☐ *** If yes,** state what mobile devices: Personal Laptop. The laptop is double password protected: device-password protection and user password protection. If the laptop gets stolen I am able to remove any files saved directly onto it remotely against my user. *** If yes,** will they be encrypted?: No
After the research	
f.	Where will the data be stored? Personal computer and password-protected hard drive storage devices.
g.	How long will the data and records be kept for and in what format? 1 year - video, audio & written documents.
h.	Will data be archived for use by other researchers? Yes ☐ * No ☒ *** If yes,** please provide details.

Section 8 Ethical issues

Are there particular features of the proposed work which may raise ethical concerns or add to the complexity of ethical decision making? If so, please outline how you will deal with these.

It is important that you demonstrate your awareness of potential risks or harm that may arise as a result of your research. You should then demonstrate that you have considered ways to minimise the likelihood and impact of each potential harm that you have identified. Please be as specific as possible in describing the ethical issues you will have to address. Please consider / address ALL issues that may apply.
Ethical concerns may include, but not be limited to, the following areas:

- Methods
- Sampling
- Recruitment
- Gatekeepers
- Informed consent
- Potentially vulnerable participants
- Safeguarding/child protection
- Sensitive topics
- International research
- Risks to participants and/or researchers
- Confidentiality/Anonymity
- Disclosures/limits to confidentiality
- Data storage and security both during and after the research (including transfer, sharing, encryption, protection)
- Reporting
- Dissemination and use of findings

1. My laptop could be stolen, therefore all the data gathered in the workshops could be exposed

Risk mitigation: My laptop is password protected. The data will be stored on an encrypted drive or server. No personal identification data will be exposed in any of the report, written analysis, articles or any other public exposure of my research results.

2. Children could be forced / coerced to participate in this recordings by school or parents

Risk mitigation: I have already visited the school and met some of the children, presented them with my project idea and they seemed excited about the prospect of participating in the research.
The children will be asked by the headmaster whether they are willing to participate ahead of the recordings.
The children will be briefed in full about what will happen in the recordings before it starts; that data will be collected and how this data will be used, both verbally and written in the information sheet provided. The assent forms the children will be asked to sign will reiterate the key aspects for which their assent is sought

Parents will be informed about the project's goals through a similar information sheet and will be asked to sign an informed consent form similar to the children's assent form.
The key aspects for which the assent and consent are being sought will state clearly the children's option of not participating in the recordings at all and leave before the start or drop out at any point without giving any reason.
A level of sensible surveillance of the children will be put in place by myself and the school staff to identify whether throughout the course of the recordings any children seem uncomfortable in any way. We will monitor the children's reactions, level of engagement to try and identify if any children fell any discomfort or uneasiness throughout the recordings.

3. Some children might be happy to participate before the recordings start but find the activities uncomfortable

Risk mitigation: The children will be briefed in full about what will happen in the classes before they start; that data will be collected and how this data will be used, both verbally and written in assent forms they will be asked to sign. This will state clearly their option not to participate in the recordings at all and an ability to leave before the start or drop out during the recordings at any point without having to give a reason.
A level of sensible surveillance of the children throughout the data collection will be put in place by myself and the school staff to identify whether workshop any children seem uncomfortable.

Section 9 Further information

Outline any other information you feel relevant to this submission, using a separate sheet or attachments if necessary.

Attached alongside this Ethics application form are:

1. The Parent, Guardian or School Staff Information Sheet
2. The Parent or Guardian Consent Form
3. The Student Assent Form

Section 10 Attachments Please attach the following items to this form, or explain if not attached

a.	Information sheets and other materials to be used to inform potential participants about the research, including approach letters	Yes X	No ☐
b.	Consent form	Yes X	No ☐
	If applicable:		
c.	The proposal for the project	Yes ☐	No ☐
d.	Approval letter from external Research Ethics Committee	Yes ☐	No ☐
e.	Full risk assessment	Yes ☐	No ☐

Section 11 Declaration

	Yes	**No**
I have read, understood and will abide by the following set of guidelines.	X	☐

BPS ☐ BERA ☐ BSA X Other (please state) ☐

I have discussed the ethical issues relating to my research with my supervisor.	X	☐
I have attended the appropriate ethics training provided by my course.	X	☐

I confirm that to the best of my knowledge:

The above information is correct and that this is a full description of the ethics issues that may arise in the course of this project.

Name	Veronica Cucuiat
Date	24.05.2017

Please submit your completed ethics forms to your supervisor.

Notes and references

Professional code of ethics

You should read and understand relevant ethics guidelines, for example:

British Psychological Society (2009) *Code of Ethics and Conduct*, and (2014) *Code of Human Research Ethics*

or

British Educational Research Association (2011) *Ethical Guidelines*

or

British Sociological Association (2002) *Statement of Ethical Practice*

Disclosure and Barring Service checks

If you are planning to carry out research in regulated Education environments such as Schools, or if your research will bring you into contact with children and young people (under the age of 18), you will need to have a Disclosure and Barring Service (DBS) CHECK, before you start. The DBS was previously known as the Criminal Records Bureau (CRB)). If you do not already hold a current DBS check, and have not registered with the DBS update service, you will need to obtain one through UCL.

Ensure that you apply for the DBS check in plenty of time as will take around 4 weeks, though can take longer depending on the circumstances.

Further references

The www.ethicsguidebook.ac.uk website is very useful for assisting you to think through the ethical issues arising from your project.

Robson, Colin (2011). *Real world research: a resource for social scientists and practitioner researchers* (3rd edition). Oxford: Blackwell.

This text has a helpful section on ethical considerations.

Alderson, P. and Morrow, V. (2011) *The Ethics of Research with Children and Young People: A Practical Handbook.* London: Sage.

This text has useful suggestions if you are conducting research with children and young people.

Wiles, R. (2013) What are Qualitative Research Ethics? Bloomsbury.

A useful and short text covering areas including informed consent, approaches to research ethics including examples of ethical dilemmas.

Departmental use

If a project raises particularly challenging ethics issues, or a more detailed review would be appropriate, you may refer the application to the Research Ethics and Governance Administrator (via IOE.researchethics@ucl.ac.uk) so that it can be submitted to the Research Ethics Committee for consideration. A Research Ethics Committee Chair, ethics representatives in your department and the research ethics coordinator can advise you, either to support your review process, or help decide whether an application should be referred to the Research Ethics Committee.

Reviewer 1		
Supervisor name	Rose Luckin	
Supervisor comments	Well written and thorough application	
Supervisor signature	[redacted]	
Reviewer 2		
Advisory committee/course team member name	[redacted]	
Advisory committee/course team member comments	This is a thorough ethics application which considers the key issues that may arise during research and it provides concrete strategies for mitigating the possible risks. I am happy to approve.	
Advisory committee/course team member signature		
Decision		
Date decision was made		
Decision	Approved	☐
	Referred back to applicant and supervisor	☐
	Referred to REC for review	☐
Recording	Recorded in the student information system	☐

Once completed and approved, please send this form and associated documents to the relevant programme administrator to record on the student information system and to securely store.

Further guidance on ethical issues can be found on the IOE website at http://www.ucl.ac.uk/srs/research-ethics-committee/ioe and www.ethicsguidebook.ac.uk

Appendix F

Teacher Data Ethics Application Details

Doctoral Student Ethics Application Form

Anyone conducting research under the auspices of the Institute of Education (staff, students or visitors) where the research involves human participants or the use of data collected from human participants, is required to gain ethical approval before starting. This includes preliminary and pilot studies. Please answer all relevant questions in simple terms that can be understood by a lay person and note that your form may be returned if incomplete.

Registering your study with the UCL Data Protection Officer as part of the UCL Research Ethics Review Process

If you are proposing to collect personal data i.e. data from which a living individual can be identified **you must be registered with the UCL Data Protection Office before you submit your ethics application for review**. To do this, email the complete ethics form to the UCL Data Protection Office. Once your registration number is received, add it to the form* and submit it to your supervisor for approval. If the Data Protection Office advises you to make changes to the way in which you propose to collect and store the data this should be reflected in your ethics application form.

Please note that the completion of the UCL GDPR online training is mandatory for all PhD students.

Section 1 – Project details

a. Project title Using Learning Analytics To Expose And Better Support The Practice-Based Teaching And Learning Process In Stem Education
b. Student name and ID number (e.g. ABC12345678) CUC14133863
c. ***UCL Data Protection Registration Number** Enter text
    a. Date Issued: Enter text
d. Supervisor/Personal Tutor Professor Rosemary Luckin
e. Department Department of Culture, Communication and Media UCL Institute of Education
f. Course category (Tick one) PhD ☒
    EdD ☐
    DEdPsy ☐
g. **If applicable**, state who the funder is and if funding has been confirmed
    Bloomsbury Colleges PhD Studentships

h. Intended research start date 20th April 2020

i. Intended research end date 20th April 2021

j. Country fieldwork will be conducted in UK

k. If research to be conducted abroad please check the Foreign and Commonwealth Office (FCO) and submit a completed travel risk assessment form (see guidelines). If the FCO advice is against travel this will be required before ethical approval can be granted: *UCL travel advice webpage*

l. Has this project been considered by another (external) Research Ethics Committee?

Yes ☐ External Committee Name: Enter text

Date of Approval: Enter text

No ☒ ***go to Section 2***

If yes:

- Submit a copy of the approval letter with this application.
- Proceed to Section 10 Attachments.

Note: Ensure that you check the guidelines carefully as research with some participants will require ethical approval from a different ethics committee such as the National Research Ethics Service (NRES) or Social Care Research Ethics Committee (SCREC). In addition, if your research is based in another institution then you may be required to apply to their research ethics committee.

Section 2 - Research methods summary (tick all that apply)

☒ Interviews

☐ Focus Groups

☐ Questionnaires

☐ Action Research

☐ Observation

☐ Literature Review

☐ Controlled trial/other intervention study

☐ Use of personal records

☐ Systematic review **– if only method used go to Section 5**

☐ Secondary data analysis ***– if secondary analysis used go to Section 6***

☐ Advisory/consultation/collaborative groups

☐ Other, give details: Enter text

Please provide an overview of the project, focusing on your methodology. This should include some or all of the following: purpose of the research, aims, main research questions, research design, participants, sampling, data collection (including justifications for methods chosen and description of topics/questions to be asked), reporting and dissemination. Please focus on your methodology; the theory, policy, or literary background of your work can be provided in an attached document (i.e. a full research proposal or case for support document). *Minimum 150 words required.*

Open-ended project-based learning activities are rooted in constructivist, student-centered, growth-based pedagogies which emphasise a trial and error learning process over perfect end results. However, teachers find it difficult to interpret these learning experiences and make sense of students' progress. The main research goal is to explore the ways in which teachers interpret different types of data visualisations of the students' experimentation process from open-ended projects using physical computing kits. The two main research questions to be explored in interviews with teachers are:

1. What is the teachers' interpretation of different data representations of students' experimentation process in open-ended projects using physical computing kits?
2. What aspects do teachers identify as relevant to incorporate into the evaluation of open-ended projects using physical computing kits?

I will be interviewing teachers to evaluate and interpret the information from a range of data visualisations which represent students' journey when building using physical computing kits. I will ask a set of questions which use the visualisations as a means of exploring the students' experimentation, in the set of practical examples. The visualisations are used as 'objects to think with' to present teachers with practical concrete information around which to structure the discussion towards the target research concepts. The interview will be conducted online via video-call, and it will follow a specific evaluation form with pre-set interview questions, however additional questions may be added as follow-up from the teachers' responses. The semi-structured interview method was chosen as most applicable to guide the conversation with the teachers around the aspects targeted by the research goals, whilst leaving some space to further detail specific answers. Each interview is scheduled to last an hour, and it is aimed at teachers already familiar with open-ended projects using physical computing kits, with a basic level of experience and expertise. The research is targeted at around 20-30 teachers, depending on availability.

The interview will be conducted online via video-call. The online video-call interview will be video and audio recorded to help me capture your responses and analyse these. If appropriate, during the interview I might ask questions which are not listed in the form but are related to the given answers. Once the interview is finished, the recording will be stored locally offline, on the researcher's personal device and/or on external data storage devices. The data in the video-call recording will be in my possession and my control for the entire duration of the project, and will only be accessed by myself, Veronica Cucuiat, the person conducting the research – this means that no one else will be able to see it or use it. No individual will be mentioned specifically in any of the research results and no reference to any personal details will be made at any point. The teachers' responses will be analysed, in writing, and included in the written analysis of my PhD thesis and potential journal or conference articles. The results of the data analysis will be made available to the wider audience through the written dissertation report and a research publication, in their anonymised format. The interview will be conducted with the teachers' privacy, safety and comfort as a priority. The teacher will have the option to opt out of the recordings at any point without explaining why.

Section 3 – research Participants (tick all that apply)

☐ Early years/pre-school

☐ Ages 5-11

☐ Ages 12-16

☐ Young people aged 17-18

☒ Adults please specify below

☐ Unknown – specify below

☐ No participants

Teachers with some experience teaching in open-ended projects using physical computing kits.

Note: Ensure that you check the guidelines carefully as research with some participants will require ethical approval from a different ethics committee such as the National Research Ethics Service (NRES) or Social Care Research Ethics Committee (SCREC).

Section 4 - Security-sensitive material (only complete if applicable)

Security sensitive research includes: commissioned by the military; commissioned under an EU security call; involves the acquisition of security clearances; concerns terrorist or extreme groups.

a. Will your project consider or encounter security-sensitive material?
   Yes* ☐ No ☒
b. Will you be visiting websites associated with extreme or terrorist organisations?
   Yes* ☐ No ☒
c. Will you be storing or transmitting any materials that could be interpreted as promoting or endorsing terrorist acts?
   Yes* ☐ No ☒

* *Give further details in **Section 8 Ethical Issues***

Section 5 – Systematic reviews of research (only complete if applicable)

a. Will you be collecting any new data from participants?
   Yes* ☐ No ☐
b. Will you be analysing any secondary data?
   Yes* ☐ No ☐

* *Give further details in **Section 8 Ethical Issues***

*If your methods do not involve engagement with participants (e.g. systematic review, literature review) **and** if you have answered **No** to both questions, please go to **Section 8 Attachments.***

Section 6 - Secondary data analysis (only complete if applicable)

a. Name of dataset/s Enter text
b. Owner of dataset/s Enter text
c. Are the data in the public domain?
   Yes ☐ No ☐
   ***If no,** do you have the owner's permission/license?*
   Yes ☐ No* ☐

d. Are the data special category personal data (i.e. personal data revealing racial or ethnic origin, political opinions, religious or philosophical beliefs, or trade union membership, and the processing of genetic data, biometric data for the purpose of

uniquely identifying a natural person, data concerning health or data concerning a natural person's sex life or sexual orientation)?
Yes* ☐ No ☐

e. Will you be conducting analysis within the remit it was originally collected for?
   Yes ☐ No* ☐
f. **If no**, was consent gained from participants for subsequent/future analysis?
   Yes ☐ No* ☐
g. **If no,** was data collected prior to ethics approval process?
   Yes ☐ No* ☐

* *Give further details in **Section 8 Ethical Issues***

*If secondary analysis is only method used **and** no answers with asterisks are ticked, go to **Section 9 Attachments.***

Section 7 – Data Storage and Security

Please ensure that you include all hard and electronic data when completing this section.

a. Data subjects - Who will the data be collected from?
   Teachers
   What data will be collected? Please provide details of the type of personal data to be collected
   - Teacher's name and email address will be used to contact them for the interview.
   - The teachers' names will be associated with each interview recording.
   - Their answers to the research evaluation interview questions will be recorded in audio-video format related to the research topic, which does not contain any personal data.

Is the data anonymised?	Yes ☒ No* ☐
Do you plan to anonymise the data?	Yes* ☒ No ☐
Do you plan to use individual level data?	Yes* ☐ No ☒
Do you plan to pseudonymise the data?	Yes* ☒ No ☐

* *Give further details in **Section 8 Ethical Issues***

b. **Disclosure –** Who will the results of your project be disclosed to?
   PhD supervisors, PhD Thesis viva panel, any journal or conference audience
   Disclosure – Will personal data be disclosed as part of your project?
   No

c. Data storage – Please provide details on how and where the data will be stored i.e. UCL network, encrypted USB stick**, encrypted laptop** etc. Encrypted laptop, encrypted external storage for backup.

*** Advanced Encryption Standard 256 bit encryption which has been made a security standard within the NHS*

d. **Data Safe Haven (Identifiable Data Handling Solution)** – Will the personal identifiable data collected and processed as part of this research be stored in the UCL Data Safe Haven (mainly used by SLMS divisions, institutes and departments)?
Yes ☐ No ☒

e. How long will the data and records be kept for and in what format?
Until the end of the PhD, scheduled for May 2021, in the same format as originally recorded as an audio-video recording.

Will personal data be processed or be sent outside the European Economic Area? (If yes, please confirm that there are adequate levels of protections in compliance with GDPR and state what these arrangements are)
No

Will data be archived for use by other researchers? (If yes, please provide details.)
No

f. If personal data is used as part of your project, describe what measures you have in place to ensure that the data is only used for the research purpose e.g. pseudonymisation and short retention period of data'.
- Collection of minimum personal data, restricted to the absolute necessary information – name & email - required to reach out to teachers for interviews
- Local and offline storage of the interview recordings
- Written text analysis of the interview responses with no personal references to any individuals
- Pseudonymisation and short retention period of data, to be removed after the completion of the PhD study

* *Give further details in **Section 8 Ethical Issues***

Section 8 – Ethical Issues

Please state clearly the ethical issues which may arise in the course of this research and how will they be addressed.

All issues that may apply should be addressed. Some examples are given below, further information can be found in the guidelines. *Minimum 150 words required.*

- Methods
- Sampling
- Recruitment
- Gatekeepers
- Informed consent
- Potentially vulnerable participants
- Safeguarding/child protection
- Sensitive topics
- International research
- Risks to participants and/or researchers
- Confidentiality/Anonymity
- Disclosures/limits to confidentiality
- Data storage and security both during and after the research (including transfer, sharing, encryption, protection)
- Reporting
- Dissemination and use of findings

1. My laptop could be stolen, therefore all the data gathered in the interviews could be exposed

Risk mitigation: My laptop is password protected. The data will be stored on an encrypted drive. No personal identification data will be exposed in any of the report, written analysis, articles or any other public exposure of my research results.

2. Teachers' understanding of the implications of participating in the research

Risk mitigation: Ahead of the interviews I will include consent questions and details in my consent form to ensure participants are fully aware of the implications of participating in the research. For teachers, as they are adults they can grasp what this means.

Please confirm that the processing of the data is not likely to cause substantial damage or distress to an individual

Yes ☒

Section 9 – Attachments. *Please attach the following items to this form, or explain if not attached*

a. Information sheets, consent forms and other materials to be used to inform potential participants about the research (List attachments below)

   Yes ☒ No ☐

   Information sheet

   Consent form

b. Approval letter from external Research Ethics Committee Yes ☐
c. The proposal (‘case for support’) for the project Yes ☐
d. Full risk assessment Yes ☐

Section 10 – Declaration

I confirm that to the best of my knowledge the information in this form is correct and that this is a full description of the ethical issues that may arise in the course of this project.

I have discussed the ethical issues relating to my research with my supervisor.
Yes ☒ No ☐

I have attended the appropriate ethics training provided by my course.
Yes ☒ No ☐

I confirm that to the best of my knowledge:

The above information is correct and that this is a full description of the ethics issues that may arise in the course of this project.

Name Veronica Cucuiat

Date 13/04/2020

Please submit your completed ethics forms to your supervisor for review.

Notes and references

Professional code of ethics
You should read and understand relevant ethics guidelines, for example:
British Psychological Society (2018) *Code of Ethics and Conduct*
Or
British Educational Research Association (2018) *Ethical Guidelines*
Or
British Sociological Association (2017) *Statement of Ethical Practice*
Please see the respective websites for these or later versions; direct links to the latest versions are available on the Institute of Education Research Ethics website.

Disclosure and Barring Service checks

If you are planning to carry out research in regulated Education environments such as Schools, or if your research will bring you into contact with children and young people (under the age of 18), you will need to have a Disclosure and Barring Service (DBS) CHECK, before you start. The DBS was previously known as the Criminal Records Bureau (CRB). If you do not already hold a current DBS check, and have not registered with the DBS update service, you will need to obtain one through at IOE.

Ensure that you apply for the DBS check in plenty of time as will take around 4 weeks, though can take longer depending on the circumstances.

Further references

The www.ethicsguidebook.ac.uk website is very useful for assisting you to think through the ethical issues arising from your project.

Robson, Colin (2011). *Real world research: a resource for social scientists and practitioner researchers* (3rd edition). Oxford: Blackwell.
This text has a helpful section on ethical considerations.

Alderson, P. and Morrow, V. (2011) *The Ethics of Research with Children and Young People: A Practical Handbook.* London: Sage.
This text has useful suggestions if you are conducting research with children and young people.

Wiles, R. (2013) What are Qualitative Research Ethics? Bloomsbury.
A useful and short text covering areas including informed consent, approaches to research ethics including examples of ethical dilemmas.

Appendix G

Audio Recordings Students Transcript

Lesson 1 - 11th September

Teacher K (presenting to the whole class): "It's great to see all the different ideas. It's also great to see how you're changing these as you go along. I'd like to see the ones you started with, as well as those that are now coming together, so don't upload just the current ones, upload all your previous ideas. It will be very interesting to see how you evolve. Whatever you are thinking now, it will keep getting refined and refined and refined."

Student L (presenting to the rest of their peers): "I'm thinking of a game like Guess Who? It might be in a pack of cards. Do you know Cludo? It will have cards like that, and you pull out a card, and you say it or show a picture or something, and you have to guess what it is. And based on how well they do, they'll get points. If they answer quickly they'll get 5 points, if they take their time they'll get less points. At the end, based on how well they do, we crown someone, so they'll become Elizabeth the 1st or something."

Student J (presenting to the rest of their peers): "I was thinking of doing a Snakes & Ladders game, like a Snakes & Ladders quiz. There's 6 lines and 10 squares in each line. There are questions on every square, related to each of Henry's wives. And if you fail one of the questions, at the end, you swap onto the next character. At the end of each line the punishment is according to each of Henry's wives: beheaded, divorces, etc. And if you fail a question the punishment on square ten moves to square nine."

Student A (presenting to the rest of their peers): "I'm thinking of doing a Monopoly type game. There will be questions and if you get the question right you can move forward, and if you get the question wrong you pick a punishment card, and whatever the punishment is you have to do choose: go to the dungeon, pay some money to get out."

Student N (presenting to the rest of their peers): "I'm doing 'Wives and Ladders'. Instead of snakes there are axes. Inside the pizza box there will be a wheel underneath, that will move underneath, that you have to move with a die roll, but you only get to roll the die if you get the question right. If you get the question wrong you keep rolling the dice until you get one right."

Student Ad (presenting to the rest of their peers): "I've invented my own game. It's got the questions and you have to move up. Say you're on 7, and you roll a 6, if you get the question right then you move up to 13, otherwise you go back to 1. And eventually you go round the board. I was going to add voice recordings, with the SAM cloud recordings. I'm not quite sure how we're going to do that, but when you land and the question is 'How many wives did Henry the VIII-th had?' it will come out of the SAM block."

Student E (presenting to the rest of their peers): "I'm going to do a Monopoly board, but with the Tudors. So there will be different properties, places from the Tudors. You will be able to roll a dice or an electronic dice or whatever. When you land on one of the boxes, there will be a question, and if you get the question right you will be able to buy the property, but if you get it wrong it comes up with a 'bad luck' type thing, and information about the answer. And if you get enough questions right, like 10 in a row or something, you get enough Tudor money to buy a hint. So that if you're really stuck on a question and you really want the property, you can use the hint. It won't give you the exact answer, it will be something related to it. There will be SAM effects, we haven't really sorted that out yet, but in real Monopoly you have things in the corners like Parking and Jail. There will be sound effects when you land on it, like a 'Dum Dum Dum' or a dungeon or something."

Teacher K (presenting to the whole class): "Don't worry about the how, or even how the technology will work. This was just getting some ideas together of how it may end up and what might be possible. You're going to develop this week after week and you're going to have time to modify it all along. Keep changing those ideas, revising those ideas, testing those ideas. You might come out with something completely different than you started with. This was about getting you thinking and started. This is not going to be how it's going to end up."

"This is an important one. As you develop your ideas, the documentation, the recording of how your ideas develop is incredibly important. You're going to need to take screenshots and photographs of all the different stages you go through and how you change your ideas. Because they have to go up into SeeSaw, and we're going to be reflecting on them. Because part of learning how to develop ideas is how to reflect and evaluate those ideas, the actual creation process."

Teacher K (just to me when all the boys have gone at the end of the lesson): "One of the biggest things they are learning is how to reflect, how to take an idea and develop it. What I want them to be able to do is handle a bigger open-ended project."

Lesson 2 - 18th September

Teacher K (presenting to the whole class): "What is the project? What are we trying to do?"
Student Ad: "Use SAM to make an educational board game about the Tudors that will help other children revise."
Teacher K: "Others and who else?"
Student Ad: "Us"
Teacher K: "Yes, you, because you're actually doing the Tudors at the moment."

Teacher K (presenting to the whole class) <talking about ways of approaching the project, references to trial&error>: "Making sure you take it in small chuncks. You will be approaching it the same way as designers and engineers in the real-world would, like Researcher. There's a lot of planning it, thinking about it, testing it, adapting it, changing it and going back."
"At the end when we look at the final projects, look back on what you each started with. Will it be anything like what you produce at the end? Did you change things dramatically along the journey?" "You're going to need to keep flexible throughout the stages of the game. We're going to keep going back and change things. What you've got now, do not be afraid to change those ideas when you get your feedback."

Children: <chuckling in the background at the idea of these changes>

Student L (just to Teacher K): "I don't think my initial drawings are very good. I don't think they represent what I'm thinking as much. Can I just write a note about what I'm thinking?"
Teacher K <challenging that 'not good enough', and suggesting a way forward: "Why not good enough? Why don't you upload the images with a written explanation and clarification of what you're going to do?" "It doesn't matter at this point. Your plans are fluid. Student L I hope you get to the end of the project and think back on what you thought at the beginning and how different it turned out in the end."

Teacher K (presenting to the whole class): "The beauty of having a class journal is that now you're able to see other's comments about your game."

Student J (to classmate): "I don't know how to present my idea. It seems too simple. And I don't know how SAM is even going to get incorporated into that."
Student J: "Yes, I was thinking if you fail a question, the end point gets <indistinct> in the light. But if you had the end point as a light, you'd need 56 lights on the board, which is a bit ridiculous."
Student J: "I can't think of a good game...I could make a game like Monopoly Tudors, but that's not original."
Student J: "Oh, I know what I can do. I could do Trivial Pursuit."
Student Kr: "You could do Scrabble."
Student J: "No... that won't work. Or I can do PacMan or something like it."
Student Kr: "Oh yeah, and you can have PacMan pieces."

Teacher K (to Student J): "Student J, what's happening?"
Student J: "I've put our inital drawing up, but I don't think it's going to be possible. So I'm trying to find other ideas."

Student J (to Student Kr): "I'm gonna try to create more ideas."

Student J (to Teacher K): "Mrs K, is there a counter in SAM? Yes!!! Instead of doing lights, I can do a counter of how many moves you've got left."

Student J (to classmate): "So Krish, this is the game I've got. So I've got questions. There's 6 people in the game, like the 6 wives, and there's a question for every square. Every square, every lines goes back further and further. So if you fail a question, the end of the line comes up here. So if you fail on eight, the lines moves here. I can do all of it."

Student J (to Researcher): "So I''ve decided... before I was going to do lots of lights but then I realised that's not possible. But then I realised I can get small counters, we're going to have numbers of each of the pizza boxes, so if you fail a question, there'd be two buttons for true or false. If you fail, it will make the number on the counter one less, so the end is closer. Whatever one you end on, the next player starts on, and you have to try to get to the end. And at the end, there will be a few extra questions on Henry the VIII, and then I think you might do something else at the end of it."
Researcher: "That sounds like a good plan. So how are you going to use SAM in that?"

Student J: "So I'm going to use SAM for the buttons and the counters. I also think at the end, I can have a speaker of some sorts that you can fit next to the character. If you move it there can be a SAM sensor in that place, so if you move it, it will play a sound"

Student J (SeeSaw video): "I am making a game called the King of Tudors. The game I am making is a checkered board and there are 6 players and 60 squares. The first player will be Henry's first wife and so on. And at the end there will be the punishments for the wives: beheded, divorced, died, beheded, divorced, survived. As a player, the red circle at the bottom means that they are red, next player will be yellow, next player will be green, next blue, and final purple. Hopefully people like it as it is a competitive game and many people like competitive games nowadays. There are 10 questions, and a starting point, and then a question for each square.
The first player is Henry's first wife, and they will be asked a question on each square, and if they fail to answer the question they stay on the same square, but with a divorce or a beheading at the end to move the punishment further in. When the first player reaches the punishment, the next player will start in the next square after the first player's punishment took place. There will be a counter at the end of each line, which will be on 9, and then 8 if you fail a question, etc."
Student Kr: "And I will use SAM. There will be a buzzer. And 6 counters that will show what square the player ended on."

Student A (SeeSaw video): "The board itself is going to be 3D printed. There's going to be a dungeon, and it's quite similar to Monopoly.
The objective of the game is for revision, for kids in Year 7 to revise as they have important exams coming up.
I wanted it to be fun and everyone can learn not just people who like looking at things if you know what I mean. There are going to be question cards, and every random so and so spaces there will be a question. If you land on that question space you get a question card and you use that to answer the question. On the back there is the answer, so once you've answered the question you turn the card around and you see the answer.
If you get 2 questions in a row wrong in a row you have to go to jail, or the dungeon. The way to get out of that is to, either one of the answers will be a jail free card and just won't have anything else on it like in Monopoly, or it will be paid in coins. You get coins every time you get a question right, so should be quite easy to get out of jail. But if you go bankrupt you just stay in jail. If you can't pay and go, you stay in jail until eventually the other players wil the game.
No you won't, there will be questions if you stay in jail for more than 2 goes, and if you get it right you get out of jail. But the jail questions will be a lot more difficult than the ones on the board. Jail Questions we can cal them, JQs.
There are places you can buy. There are going to be characters as players going round the board, there's going to be the guard of the prison, and the 6 wives maybe?
The characters will be random people. There's going to be like places in the Tudors that you can by the properties. So for example, King Henry's place / palace (4000).
The board will be 3D printed. Every time you go round you get 100 cash.
The corners will have harder questions, if you get them you get 500. The easier questions you get 100.
The dungeon will be underneath the board, so for example like bunk beds.

I am going to use 3D printed, SAM Labs, the dice is going to be a buzzer which will buzz if you get a question right, and this buzzer will buzz how many times you can move. How many times the buzz goes, that's how many spaces you move. There won't be a routine, it will be randomly generated.”

Student A (SeeSaw video number 2):
“I am going to be doing a design specification for our game.
Audience: Our game is going to be for Year 7 students. It's going to be about the Tudors as Year 7s learn about the Tudors. It's going to be a revision game / revision resource who don't like revising.
Objective: Our objective is for Year 7 students to revise the Tudors. It's literally just for revision.
This is what the board is going to look like but a lot neater, I just drew this quickly, Q here, Q here, Q here. It's going to have a beheading center, so if you land on a square you have to go to the behending center and you have to pay to get out. You get money for answering questions right. It's going to be made out of a pizza box.
We're going to use SAM and 3D printing. We are going to use SAM for the dice, I will have a Button and a Buzzer. When you press the button the buzzer will buzz how many times you move. You can't just press the button 6 times to move 6 spaces. When you press the button a random number will be generated and the buzzer will buzz how many times you move.
Times needed: a few weeks for the 3D printing, getting the characters etc."

Student N (SeeSaw video): "My game is Wives and Ladders. It's similar to Snakes & Ladders but with axes instead of snakes. It's going to be like a regular Snakes and Ladders board, with normal squares, and all the characters are going to be Henry VIII's wives. Say this is the start, this is the finish, and you went this way. If you answer a question correctly, you go on SAM Labs and use a random die roll. The first one to get to the finish gets to marry Henry."
Student N: "I don't know how we'll make the game intelligent. I've got the die roll, once you start. But I can't think of anything else."
Teacher K: "We'll get to that later but you can do something with the way in which players move around the board.."
Student N: " Oh yeah yeah we could.."

Student L (to classmate): "It's going to be like the actual Guess Who, and to help you we'll have hints. If you press hint, then you'll be given one."
"But you only get one go. So either you get to answer the question for the other person, or ..."
"Guess Who Tudor, pictures than facts and you must guess who the person in the picture is. We will have a picture first. If you don't know you press a button and a recorded hint will play."
"A board game mainly based on Guess Who game. There will be picture of the people such as kings and queens. You can either ask the other person a question about they appearance, or you can press a button for a voice recorded hint."
"I don't know how we'll do that. How will we actually do the hint? On a SAM? Although we might need a lot. Maybe we do do it just for one, you're only allowed one hint per Tudor."

Student L(SeeSaw video): " I am building a Tudor game to help students revise for their history exams. It's going to be about the 5 second rule, which is a game where you answer questions to move up on the board and win. We are making this to help students revise, but it's especially for year 7. We think it will look a bit like this. On your turn, you will be able to answer questions, and if you get it right, you can spin a spinner with numbers 1 to 4 on it, and whatever number you get you go forward that. To make it more fun, with a normal board game you'd have some squares that if you land on them you go back. It's the same with us, so we do have that. The way we will incororate SAM Labs into this is we will have buzzers, to buzz for your question, and a timer for the 5 second rule, so you have 5 seconds to answer. "

Student F <responding to critisism about his writing of his draft>: "It wasn't supposed to be final, it was just like a sketch.."

Student Ad <in response to Teacher K's question about what the boys learnt from others' comments of their work uploaded in SeeSaw>: "Most of my comments were questions, so they didn't give me any ideas, but they did help me think a bit more .... <refined (Teacher K filling in)> ... yeah."

Lesson 3 - 25th September

Teacher K: “OK, last time only Student A uploaded their video to SeeSaw. None of you did it which might be because you’re worried you don’t know what you’re going to do with your games yet.
I suspect that's because you weren't quite sure what you were doing. I've done my own and I'm going to show it to you in a minute. Then I'm going to ask you to put your design specification up.
The design specification is like your success criteria. Sometimes you have a success criteria that you tick off against, say "am I on the right track, am I doing what I should be doing"? Imagine your design specification being your success criteria. What you're actually going to do at the end to completely evaluate your product is you're going to look back on your design specification and whether you were able to match all of your specification criteria.
If you don't put your design specification, your success criteria up, you won't be able to check against it. So you need to do this first. Now what I had envisaged you doing was taking this, taking a slice down each of these, and then looking a bit like mine.
I'm going to run a few seconds of mine, and then I'm going to ask you to watch it yourselves in full. Once you've watched it and know exactly what you need to do, you can come back at lunch time or during code club to do it and upload."
Student E: "What if we've already done it?"
Teacher K: "It depends if it's the same as what I'm going to show you"
Student Ad: "Does it have to be exactly the same?"
Teacher K: "No but this might just give you just a few ideas. So I'm going to play a little bit of it and then I'm going to ask you to watch it on your own devices."
<Teacher K playing the design specification video>

Teacher K: “So I’m including quite a lot of technology in different ways aren’t I?”

Student E: “Wait, can you do.. Can you land on a pressure pad?”
Teacher K nodding

Student E: “No one’s sort of decided what they’re going to do with the SAMs yet”
Teacher K: “Well this is why I’m giving you some ideas”
Student E: So we’re allowed to use some of these ideas?”
Teacher K: (whispering to let the video audio be heard) “We’ll discuss it later...” (but never picked it back up)
Teacher K: “The video is just an idea of what you should be doing… just a few ideas of the kind of things you should be doing”

Student E: “So we won’t be able to take them home?”
Teacher K: “Ahm.. you can take the boxes home… and you practice with the SAMs in the classroom.. You might be able to take them home to revise but you have to bring them back..”
<Student E thinking about how can they test the equipment, how will the testing actually work>
Student E: “Yeah, what you could do is note down everyone that has them at home and note it down that way”

Student Krnendu: “So when do we get the pizza boxes to draw on?”
Teacher K: “So today you’re going to work on an A3 sheet of paper, to draw it out initially, cause if you start drawing on the box and you change your mind then you can’t alter it. So you’ll do it on paper first and when you’re sure you move onto the pizza box.”
<Student K not convinced about doing it on paper.. Keen to do it directly on the pizza board - I don’t need prototypes, I won’t change anything initial feeling>

<The whole class watches the videos independently>

Teacher K: “OK so this is actually finishing up last week’s lesson, so you will come in at lunch time to finish your own design specification videos. What you didn’t do last week is you didn’t put up your success criteria, so you're’ going to need to do it this time. If you think you did it last week, what would be really helpful is put up the first version like Student A and Student Ew did, because you will see the difference between your first version and your second version, and it will be really interesting to see the development. Does everybody understand? Put the first version up on SeeSaw and do the new one and upload that one as well. And that will be your success criteria.
<emphasising the value of the change between versions specifically!!!>
<no students put up an initial & second version except Student A & Student Ew because they had already uploaded it by the time they were asked to do a second>

Teacher K: “At the end of every lesson, we need to do a journaling bit, like a record of your journey. Also, once you all upload your design specification videos, I will ask you to comment on each other’s videos. Not about the video itself, but about the game. Gather feedback on each others’ success criteria for the game. Once you get your feedback, if you change anything, why did you change it?”

Teacher K: “Today, I will be giving you a piece of A3 paper, for you to start drawing what your game might look like.”

Student R: “I know EXACTLY how this is going to look”
<we don’t want this… this is NOT part of our measure of success…>
Student E (looking at monopoly boards online): “It’s 9 small bits per each line. OK Student R, so there’s 9 per section.”
Student E: “It’s 9 small ones..”
Student R: “Yeah I know I know I know I know…”
Student E: “it’s too small, turn it over.”
Student R: “Wait wait, this is just a rough sketch…”
Student E and Student R together drawing their squares: “Ah, this is so annoying. I keep drawing our squared 1cm too short. I’ve done it twice now!!!”
Teacher K: “Don’t forget it’s just the first draft. Only when you paint on the box it will have to be precise”

Student E: “Is this copyright theft though? All the board games seem to be under copyright.”
Teacher K: “Strictly speaking yes, but I don’t think they’re going to chase us..”
Student E: “I don’t think we’re putting it online to sell”
Teacher K: “No, no, we’re not, we’re keeping it internal. If you sold it yes we’d have to acknowledge this is based on Monopoly etc., but we’re not going that far”

Teacher K: “How are you doing, are you alright?”
Student R: “Yeah… it’s very stressful…!” (trying to draw the board on the A3 paper and getting it wrong)
Teacher K: “Student R, don’t worry about it being absolutely perfect, because when you do it on your board, you’ll have to spend a lot of time then. Till then this is a rough copy so don’t worry”
Student R: “Where is the rubber?! Where IS the rubber?? “
(they continue to try to draw together on the same board and getting slightly frustrated about the imperfections / miscalculations - with themselves and each other)

Teacher Assistant: “Hey, how are you doing? How’s your board game coming along? What is it all about?”
Student R: “I’m just measuring our board. I’m just doing the final bit”
Teacher Assistant: “So do you want to explain your game so far?”
Student R: “So, it’s basically a Tudor Monopoly. Instead of normal Monopoly where you just get cards or a street, mine will have questions to get the property.”
Teacher Assistant: “Right, that’s a good idea. So, is the idea to still have money and everything or just the questions?”
Student R: “Yeah, it’s basically Monopoly with questions. Like if you roll 6 and 6 normally you get something you know, but wit us you have to answer a question and answer.”
Teacher Assistant: “So how will you integrate technology into it?”
Student R: “I was thinking about the money. To have a card for the money somehow.”
Teacher Assistant: “I think it’s a great idea. I don’t know how you’d do it. If you have a credit card but how to link it to your board. “

(discussion about a credit card system used from Monopoly empire.. A version of the game has a credit card for the money handling but discussing whether it would work for the game, and how they would even acquire it in the first place, neither of them have it at home)
Student E: “Right, it’s going on my bday list. And I can use it for this too”
Teacher Assistant: “So what other technology will you have?”
Student R: “SAMs”
Teacher Assistant: “OK..”
Student R: “And maybe we can 3D print too…”
Teacher Assistant: “OK, so is it just going to be 3D printing or is there any SAM going to be in there?”
Student R: “So if I could build something like a segway to move around the board...”
Teacher Assistant: “One thing to bear in mind is the width of the wheels. So the motors are quite big. Not saying it can’t be done, but it’s something to think about, because if you think of the width of the DCMotors, when you add the wheel and put them together they end up quite big, and the board is going to have to be really big.”
Student R: “Yeah, so I was thinking maybe something for the queen… but yeah… nah…” (reluctant to continue, tempted to drop the idea altogether based on Teacher Assistant’s feedback)
Teacher Assistant: “SO 3D printing pieces, sure.”
Student R: “I think that will be quite easy. Or we can forget about the SAMs, and just do it like that, like the original”
Teacher Assistant: “Well you could do both”
Student E: “Or you could you it when you hand on a square it makes a noise”
Teacher Assistant: “Aaahh, yeah, very good, yeap that’s definitely a lot easier to do”
Student R: “But we can’t take them home… “
Student E: “No but we’re allowed to maybe take them home whilst we’re revising, and then bring them back.”
(them thinking about actually using the game at home after it is built, as a long term thing)
Student R: “But then the pizza box would have to have lights and things…”
Student E: “Could you have… I don’t know how to put it… like a speaker, with SAM, to read out the question to you?”
Teacher Assistant: “Potentially, yeah.”
Student E: “Or is that hard?”
Teacher Assistant: “Not so much hard, but time consuming. Because you’d have to record all the questions, for the computer to speak them out”
Student E: “So we’d have to record the questions? Well that’s not hard..”
Teacher Assistant: “No, just a bit time consuming. But you’d also have to figure out exactly how that would work with the SAM blocks, it might be tricky to select the questions randomly for example”
Student E: “So this is what I was saying to Mrs K, we don’t know how it works. So could you have something that you land on on every square?”
(uneasy about not knowing what to do with the SAM blocks and not knowing how they work in order to plan)
Teacher Assistant: “No, not on every square, so SAM has a limit of 8 blocks that you can use at one time”
Student E: “So how would you do it?”
Teacher Assistant: “Well you wouldn’t do it for every square. You probably have special things. Like special squares, special places where you can have a pressure pad”

Student R (going back to credit cards): “Look, that’s the one with credit cards”
Teacher Assistant: “Yeap, that’s the one. The challenge is that you’re using credit cards for a Tudor game. You’re using payments in credit card for a game set back in the Tudor era. Not sure how historically accurate that would be.”
Student R: “But if I was to do the money I’d do maths… so it would be a double whammy”
Student E: “You know with the electronic things, would someone have to be handler, to work it? So like if you land on go, you get 200 pounds?”
Teacher Assistant: “Well that’s what you need to work out.”
Student E: “But I guess there’ll always be 2 people playing, you wouldn’t revise on your own.”
Teacher Assistant: “Yes, exactly. And you should put that down as part of your plans of how you’re going to do it. It’s part of your game design, if you revise together it will be more effective. It’s a really good thing to put on your specification.”

Teacher K: “Have you uploaded yours?”
Student E: “No, no, cause I’m not finished”

Student Ad (to classmate): "It's not perfect, but it's a start..."
Student F: "I'll make it an electric spinner. And on the spinner there are dots, so where it spins, the number that it lands on, that's how many spaces they move."
Student Ad: "You know that wheel thing? You know that wheel thing that span around. I can do it so that when you press a button the wheel spins, the wheel is connected to a spinner. Don't copy!! <to Student R> And I have an arrow, so where the arrow stops that's how many spaces they move. Isn't that a good idea?"
Teacher K: "OK, so what technology are you going to use?"
Student Ad: "A voice recorder. I don't know how I’m going to do it, but say you pick up a question card, it will somehow know what question you picked up, and read it out."
Teacher K: "That might be possible, might not be. Maybe it you get it to just read the question out loud, the SAM player just reads the question, you can have randomly generated questions and maybe you can do a timer to time the answers."
Student Ad: "Ohh yessss!"
Student Ad: "I thought that, so it will a hard way to remove the counter. Say a shaker, you know the shakers, and it slowly moves....it's just a slow way, so however fast you do it, the longer time you have to answer a question. Cause I can remember last year when we were doing it <working with SAM>, D did this thing that you would shake and and thing vibrated. And you have to shake really hard to get the furthest, that's the time you've got to get to the next spot."
In my own words: You have to shake to know how long you've got to answer the question. The harder you shake, the longer time you have to answer the question / move along the board.
Teacher K: "Oh I see, oh I'm beginning to understand now. Well we can try it next week. Let's try it, see if it works."
Student Ad: "However quick you do it, you might not finish.. Whatever time you did.. "

Student Ad (to classmate): "OK, so, forfeit cards. With the forfeit cards, if you land on a forfeit space, you have to forfeit. Make it a memorable game. The forfeits will be something that happened in Tudor times, but modernise it."
Student F: "Do you forfeit on a forfeit space or when you get a question wrong?"

Student Ad: "Oh good point. Which one? I was thinking if you get it wrong you go back."
Student F: "No, that's stupid"

Teacher Assistant (to Student Ad & Student F): "How are you getting on?"
Student Ad: "I was just explaining to Mrs K the characters. So you know how you the shaker, when you shake it it vibrates. So how long it takes you to get to the next spot, it determines how long you have to answer the question."
Student F: "Wait, what? No, what do you mean how long it takes you to move your hand?"
Student Ad: "You try to vibrate it. It vibrates quite slow."
Student F: "Ok so if you get 5 seconds, you only get 5 seconds to answer the question. OK."
Student F: "Ok, and if you get the question wrong, you have to get a forfeit card."

Student A (speaking to classmate): “it's the button”
Student Ew: Oh yeah yeah. What does the buzzer do?
Student A: It buzzes the amount of spaces you move.
Student Ew: No, that's the button.
Student A: No it isn't, the button doesn't buzz, does it?
Student Ew: Ohhhhh

Researcher: “How is it going? How are you incorporating SAM into it?”
Student A: “I'll have a buzzer that buzzes how many spaces you can move”
Researcher: “Ok, like an automatic dice, anything else?”
Student A: “Yeah. I'm still thinking how we're going to integrate SAM into it..”
Student Ew <original version of the ultimate ‘trapdoor'..>: “Underneath the box I have a beheading center, you know one of those boxes with spikes that closes and then you die. Something like that, although that might be a bit too gruesome.”
Researcher: “And what are you doing for the revision elements? So you have the questions, which will help me test what I do know, but they're not going to help me learn anything new. So you might want to think of mechanisms to help students learn new stuff, as well as test their knowledge.”
Student A: “I have an idea. Every two spaces there will be a fact about the Tudors..”

Student A: “What's worse? A jail or a beheading center?”
Nick: “What do you think?!?!? A beheading center of course!!”
Student Ew: “Maybe the jail actually..”
<appropriation of the ultimate goal… same functionality, but different connotations>

Student L: “So I want to have a buzzer, but it won't be on the board. It's almost to answer questions, sort of.”
Student L (to classmate): “So let's actually create the board.. Kinda like a board game. Look online ‘board game board'”
Researcher: “So what are you planning, in addition to the buzzer?”
Student L: “basically a board game where you answer questions. You know the game ‘the 5 second rule'?”
Researcher: “No, I don't think I do actually. How does it work?”
Student L: “So, you have a buzzer, someone asks a question, and you have 5 seconds to answer it. If you get it right you can roll the dice and go forward.”

Researcher: “So how are you going to help with revision? So the questions are great to test your existing understanding, but for those that don’t know the answers, how are you going to help them revise?”
Student L: “Well, they’ll be told the answers..”
Researcher: “Ok, something to think about. So in addition to the buzzer, do you have any other SAM elements?”
Student L: “Well, so I have the buzzer to answer the questions and the timer to count the 5 seconds..”
Researcher: “Nice. And what’s it going to look like, the design? What is the board going to look like?”
Student L: “I’m not sure, it’s probably … I’m going to work on that.”

Student K: “So what happens to the time when the buzzer goes?”
Student L: “So when you press the buzzer the timer stops. Or maybe you just buzz before it goes off”
Student L: “OK, let’s be super mean and let’s say square 23 is ‘back to start’. But it’s like the last one.”

Teacher K: “Right, what are you doing?”
Student L: “You know the 5 second rule game?”
Teacher K: “Oh, no I don’t actually”
Student L: “So, you ask a question, and you get 5 seconds to answer it. If you answer it right, you have a spinner or a dice and you roll it to go.”
Teacher K: “Remember you can’t have a dice. You got to have a technological replacement.”
Student L: “Can I have a spinner?”
Teacher K: “Yes, you can have a spinner.”
Teacher K: “Right, what other technology will you have in your game?”
Student L: “Just the 5 second timer and the buzzer”
Teacher K: “Oh ok, so what’s the buzzer? Is that the one you press when you have an answer?”
Student L: “Yes”
Teacher K: “So how is it going to work? Each person will have their own buzzers?”

Student Ed: “Oh, I should do …, and on some squares we should <write on the board??> and then you go through start”
Nick: “Yeah!! And some squares can have special things on them”
Student Ed: “I like how we’re doing different ideas”
Student Ed: “So Nick, there could be a sword as well.”
Nick: “Naahhh..”
Student Ed: “I could do like a cool …”
Nick: “.. Yeah.. OK”
Student Ed: “Yeah and put in the SAMs as well, I’m going to make it intelligent. And I can make question cards..”
Nick: “How would you go up the ladder?”
Student Ed: “So, you roll the dice, and you get this..”
Teacher K <interrupts> : “Instead of a dice, can you think of something interactive..”
Nick: “I was thinking we make it random.”
Teacher K: “Yeah so making a random number using SAM”

Nick: “Yeah”
Teacher K: “But you can make it look like a dice. So it can have a button in the middle of a box that looks like a dice, that generates a random number.. You can use boxes and other stuff..”
Nick: “Oh yeah..” <is interested in the idea and seems to draw it on the paper>
Teacher K: “Or you can 3D print it..”
Teacher K: “Then you can have SAM in it.”
Nick: “What, inside?”
Teacher K: “Yeah, in the box :) “
Nick: “Oh yeah <smiling>”

Student Ed: “Then I have question cards that they will have to answer”
Nick: “AAHHHHH! Not a rule book but…”
Student Ed: “The ewl *(old)* book of law”

Teacher K (presenting to the whole class): "Ok everyone, put whatever you've got up so far in SeeSaw. Take photos or write and upload it to SeeSaw in whatever format it is now, and then we'll take it in turns to talk about it. Right, has everyone uploaded to SeeSaw?"
Boys (including Student F & Student Ad): "No, we're not finished"
Boy (unsure): “Can we just put it on GDrive and project?”
Teacher K: “No because you’ll have to get feedback from the others on SeeSaw”
Student Ew reaction <Noooooooo….I haven’t finished IT!! >

Student L (presenting to the rest of their peers): "My idea is a 5 second game. Some people might not know it. Basically you ask a question, and you have 5 seconds to try and answer it. If you get it right, you can spin a spinner and move forward. And I have a Buzzer.."
Student L: "So the technology I have is the buzzer, a 5 second timer, a spinner."

Student Ew (presenting to the rest of their peers): "Ok so my game is based on Monopoly, it's not exactly the same but I’m going to do like you get asked questions every certain how many goes. Each player has its own questions, and each question is going to be harder. And if you get so many questions wrong you go to jail."
Student Ew: "Yeah, and you can get out by paying money. With each question you get you earn money, so you can get enough to get out. You can also get out by answering one of these harder questions or with a 'Get out of Jail' card. When you get a question right, you press a button and the buzzer from 1-6 will say how many spaces you can move."
Teacher K: "So, how do you win?"
Student Ew: "By forcing the other person to run out of money. If you go to jail too many times you run out of money, and if you run out of money you're out of the game."
Student Ew: "It's a 6 player game, so we're going to have 6 people playing at once. And you win if the others loose their money. You loose your money by going to jail. So if you get 3 questions wrong in a row, you go to jail and you have to pay to get out."

Student Ed (presenting to the rest of their peers): "Our game is called Wives and Ladders. You have Henry and his wives. You roll a random die roll somehow using SAM. You go through the board, and there are these questions marks, if you land on them you have to answer a question. The laddes you go up, the axes you go down. On this space, two characters switch where they are, just to add a surprise element. You also have the executioner, which means you have to answer 5 questions correctly, or you go to the dungeon. I'll have a random die roll, if someone lands here there's going to be a buzz, for each question. Using the pressure pad, it will activate the SAM voice to read the question. "

Student J (presenting to the rest of their peers): "My game is called The Tudors. So there are 60 spaces, and there are going to be 6 players. If you start with the first question, and you get it, this <presumably the end of the line punishment> will stay still. If you get the question wrong, you stay still and this <the punishment> will come closer so your death point it closer. There's going to be a Counter showing the numbers at which the death point is, and there will be cardboard cut-out and 3D printed pieces. So every question you get right is a point. Once you get a point, you count the points out and at the end, you have to face Henry with some questions. If you get the first quetsion wrong, the person with the second largest amount of points can answer. So the second or third person also have a chance."
Student J: "I'm going to have a counter to count where the SAM end is. I'll also have two buttons, which will be either True or False. There will be sounds, such as Corect, or False. At the end, there will be a SAM for each wife, so for each punishment: behedeaded, divorced, etc."
Student J: "So there's a question on each square. And you roll. And once the end point is reached, the next character moves on to the next line. Whoever has the most points goes on to have some questions about Henry, but if they fail the questions, the next player will go on and gets all the Henry questions in his place. So there are 6 players for each wife, and each player has a line. You could have 3 players, and each player would be 2 wives, so take 2 lanes. "

Student E & Student F - I don't have their presentations to the class from the third lesson since they didn't get the chance to present during the lesson as they ran out of time, and they presented in a different lesson / lunchtime where it wasn't recorded

Lesson 4 - 2nd October

Teacher K: "Today, you're going to sketch out your ideas of what you THINK you players are going to look like. Then, we have two software to help us: Thingyverse and Tinkercad. Tinkercad is making it from scratch, how you made your keyring. Thingyverse is what other people have made in Tinkercad and uploaded for anyone to use. You download an example and adapt it. Let's not reinvent the wheel, let's find something that suits and adapt it, to make the best use of time."

Teacher K: "Ok, each take it in turn to present what you've uploaded in SeeSaw. I'm actually going to video you, Student E, would you mind being the videographer as everyone presents?"
Student E: "Yes, I'll record on my iPad"
<Teacher K 1) specifically makes SeeSaw uploading time as part of the lesson, and 2) actively uses SeeSaw uploads as part of the lesson for students to present and comment on 3) records videos of the students, to have records of their journey as they go through it.>

Student J (presenting to his peers): “So we have 4 characters, so 4 wives. Each character will be the same with a different name on the base at the bottom.”
Teacher K: “OK, so similar idea to N, very good. So let’s see what comes up on Thingyverse, because depending on what’s available you might change your ideas. Fantastic, very good idea.”

Student N (presenting to all peers): “My game is called Wives and Ladders. Each character that you play is one of the wives of Henry the VIII. Since we have enough colors for the 3D printing, each wife will be a different color so you can differentiate between them.”
Teacher K: “OK. One thing you said to me earlier was that you were looking to do each one individually, but what did you say to me?”
Student N: “They are going to be all the same”
Teacher K: “So rather than having to find 6 different models, if you can find a really good lady as a Queen, you can tweak and adapt a little bit for each one, but you can take each design, change the color and maybe the plaque at the bottom, and maybe just tweak the design of each one. So instead of building 6 different models from scratch, you can take one main model and tweak it and use the color and labels to differentiate. And that’s a very good use of the time. You are using it effectively, without taking ages and ages just on the design.”
Teacher K: “That’s great N, thank you!”

Student L (presenting to his peers): “My characters are going to be Henry the VIII, Elizabeth, executioner, Shakespeare. The executioner is going to have a mask.”

Student A (presenting to his peers): “I’m going to have a piece which just sits on the board, Henry, and 4 wives. For the piece, they are going to have a face, and they are going to be standing up on a base.”

Student Ad (presenting to his peers): “I’m going to have a big Henry character, and Elizabeth, Lady Grey Jane, etc. And then also Teacher Assistant gave me an idea that I haven’t drawn yet that I could do coins for the Tudor characters. So I could have 5 or 6 coins instead of doing the characters like that.”
Teacher K: “Brilliant, that might be easier, especially if you don’t find those characters on Thingyverse. Yes, well done.”

Student R (addressing Mrs K): “Mrs K, could you print out that Tudor house?”
Teacher K: “Ahm, yes you can, but not today. So pick it out and plan what you want to do and next lesson we’ll start printing”
Student E: “Can I resize them”
Teacher K: “Yes you can, in Tinkercad you can take it and adapt it however you want”
Student E: “Yeeeahh, cause you have all the houses in Monopoly, so they need to be really small”
Teacher K: “Yeah yeah yeah, you can do that”

Student R: “Could I get our original plan <assuming that is the A3 paper drawing they did last lesson>, just to see how big roughly they need to be?”

Teacher Assistant: “That’s it, you need to think about that, how big it needs to be.”
Student R: “I’ll go ask Mrs K”
Teacher Assistant: “Well just have a think, you don’t need to go ask Mrs K <although Student R wasn’t going to ask about the size, he was going to ask for his drawing>, how big do you think it would need to be?”
Student R: “About 2X3 cm…?”
Teacher Assistant: “OK. So we can do all that from here, no need to ask Mrs K.”

Lesson 5 - 9th October

Teacher K: “We’re getting to a stage where different things will be going on with different groups. So it’s becoming less structured, because you’ll be starting with your own projects and you’ll be working at different stages on different parts of the game. But, hopefully, these are the sort of learning expectations that you feel you have covered so far: we’ve got 1) understanding the basics of 3D printing and the basic functions of a 3D printer. So here we’re ‘using a computer program to complete a fairly accurate representation of a more complex design’. We are not doing exactly that, we are taking Thingyverse designs and adapting them, but we are using TinkerCAD to finalise.
And here, we are starting to research and come up with possible solutions for a problem - that’s our whole boardgame itself. We’re going to be working on prototypes and design the best design possible. Why have I got that last sentence in red? <the last sentence is something related ot evaluation’> Why have I got that sentence in red?”
Student L: “Because we haven’t evaluated anything”
Teacher K: “That’s it. We haven’t evaluated anything. We have posted a few things on SeeSaw, and I like the way people are posting & commenting, but we’re not quite there in terms of evaluation. What we’ve got in SeeSaw atm is good, our board pieces, our initial prototypes, people presenting their ideas, but what we haven’t done enough of is we haven’t explored and fed back on what we’ve done so far.”
Teacher K: “What I hoped you’d be doing is taking pictures of every stage, posting on SeeSaw, writing about these …, record everything you’re doing and be really aware of the journey you’re going through. What you’ve changes, what you’ve worked on, what you’ve adapted. SeeSaw is your individual learning journal. You should be in the process and learning from it. You should see your own journey of going through this process. You should be aware and be in the process, able to reflect on it. Aware of it, of how much you’re changing, adapting, what you’re learning as you go along, which learning expectations you’re covering. You should be able to talk about it and tell me at the end exactly how much you’ve progressed, what you’ve learnt from it.”
(video paused for 10ish minutes due to Teacher K freezing everyone’s screen for them to pay attention - maybe check the CCTV)
Teacher K: “And atm, not all of you can show me. It’s not your fault, because we’re short of time, but I think we can be better at it. We’ve only got one more week before half term, but we can do more of it during the xmas period.”
Teacher K: “I want you to do some exploring, and testing, and finding out for yourself in this one. You’ve had lots of inspirational ideas, spinners etc, now you’ve got to actually try them

and put them into practice. Some of them might not work. That's absolutely fine. It doesn't matter. It doesn't matter at all. But importantly, you have iPads, it has a camera on it, take pictures as you go along."

Student N: "Right, let's get started. I'm going to find a way to make a random number"
Student N: "Button. I've paired my button"
Student N: "Ah, this is good. Student A, there's going to be a light sensor and it's going to say what the number is when you click the button."

Researcher: "So what are you thinking of doing with SAM?"
Student N: "I'm going to do it so that there's a button that you press, and you get to click it twice, and there's red, green and blue. I'm trying to make it so that if it's green, it will be 1 move on the board, and you get to click it twice to get to 6. I don't know how to make it give a random number… "
Researcher: "OK, so you click it twice to get a number between 2 and 6. You'll never get 1, but that's fine."
Researcher: "You can write a bit of code to make it random. I could help you with that. But actually, your idea is better. Try that and then once you've got the setup, we can work on the random thing with custom code. I can help you with that."
Student N: "Yeah.. not sure if I should do it like this though cause it's kind of weird to get the light mix obviously… I'm not sure how to do it so that it's just the button, for it to come up with a number."
Researcher: "Do you mean how to actually display a number?"
Student N: "No, how to make it work even. I can't think of any ways to make it tell someone how many spaces to move forward randomly."
Researcher: "Ok, so what type of outputs do you have available in SAM that could signal the number? You can't display it, but you have lights, you have sounds…"
Student N: "That could work actually"
Researcher: "In the SAM player, you can customise the sound"
Student N: "I know, you can add your own sound"
Researcher: "So you could even record yourselves saying 1,2,3… and depending on how many times, you have 6 players, and it goes to the right one."
Student N: "Yeah yeah, but how do we make it so that it's random, it randomly goes to one of the 6?"
Researcher: "Hm….. I think your best bet is to write a bit of code."
Student N: "How would we do that?"
Researcher: "Let's try it. So…"
Student N: "Is there a way to make it choose a random number up to 6?"
Researcher: "Yes, so drag the code Code Module in, and we're going to have to do a bit of javascript googling."
Student N: "OK"
Researcher: "OK, so you need to modify the output of this function. So you want it to return from 1 to 6. So in this function, you want this variable to get a random number from 1 to 6. So let's google get random number in javascript. OK so let's plug that in..."

<Student A continuing to work on SAM stuff>
<As he's working on SAM, he eavesdrops to Student N and I's conversation from time to time>

<As Student N and I work on the code, Student A gets interested and follows the conversation>
Student A: “I’m going to work with you”
<He stops working, waiting for us to finish our testing to see what comes out, whether it will work or not>
Student A: “It sais only change the code below this line”

Student N: “Oh yey… oh that’s great. That works. YES.”
Student A: “Yeeeyyy..”
Researcher: “Boom, so, now you need to put it in SAM”
Student N: “So… what do I do?”
Researcher: “OK/.. so you’ve got the function here in SAM, so what do you copy over?”
Student N: “Add this...”
Researcher: “Right, and what do you have to put in the output of the function?”
Student N: “What do you mean?”
Researcher: “So, instead of returning the function, you return the value.. I don’t know if you do much coding atm..”
Student N: “Not much..”
Researcher: “So you initialize the variable to 0, apply the function, then return it.”
Student N: “Ah OK. So now we need to add the sounds in. But wait, how do we put it in the graph? How do we test it?”
Researcher: “No, cause we don’t have an output...” <I walk away>

Student A: “Nick can you show me the code? Nick, can you show me the code?”
Student N: “No”
Student A: “Please”
<Student N shows Student A the code>
Student N ,speaking to Student A who is copying the random function: “math.random….”
Student N: “No, you don’t need to do anything else.”
Student A: “Thank you”
Student N: “Don’t thank me… “
Student N: “No, the text block doesn’t work..”
Student N: “We have it so that it sends a number… There you go.”

<I come back>
Researcher <watching Student N trying to test the code function and find a way to embed it in the SAM graph>
Researcher: “Right, how do we do this, how do we do this..?”
Student N: “Could it have the ‘send a number’ <component> … wait does it send a number? Oh it doesn’t work”
Researcher: “yeah because it sends a number..”
Student N: “Oh yeah… nevermind, obvs..”
Researcher: “Oh I know, you can have a filter, and an output, and have the 6 of them separately..”
Student N: “And what would the filter do…”
Researcher: “SO you have a separate filter and player for each. And each filter is between 0-1, or 1-2, etc. you know?”
Student N: “How would that work..?” <places the filter on the canvas>

Researcher: “And only when it’s between 0-1 will it do something”
Student N: “Oh, yes, yes, that’s it!!”
Student N: “Yeah, but then we can have a bunch of them, like up to six, right? “
Researcher: “yeah, that’s right. I actually don’t think that’s the most efficient way of doing it, that’s one way of doing it..there might be a better way..”
Researcher: “I’m not sure this will work but we’ll test it”
Student N <reassuringly>: “We’ll test it out”
Researcher: “Oooohh, actually, what does this ‘Compare’ <component> do?”
Student N <reading the SAM label>: “Compare? Compares a value …”
Researcher: “That’s what you need isn’t it?!”
Student N: “Oh wow!! Nearly there too <with the filters>”
Student N: “OK, so would it be 1, and the next 2, etc.”
Researcher: “Yeah that’s it”
Student N: “Yes!! This is the best!!” <Researcher walks away>

Student N: <to Student A>: “You don’t need filters!”
Student A: “That’s not an output!”
Student N: “It’s a Compare”
Student A: “It’s not an output!!”
Student N: “How do you mean..? I don’t understand what you mean?!”
Student A: “You have to connect it to something else..”
Student N continues his work without answering further

Student Ew: “What, that is all you’ve done?”
Student A: “It’s harder than it looks Student Ew!!”
Student N: “Are you joking?! What have YOU done?”
Student Ew: “That’s all you’ve done?”
Student N: “Oh Student Ew, this is so much harder than what you’ve done”

Student A: “Yeah… it does not work like that...you have to connect it to something”
Student A: “And you need a sound to connect to it…”
Student A: “If this works, it’s all my idea, OK?”
Student N: “But if it doesn’t…”
Student A: “It’s all yours”
Student A: “Nick, I knew your idea wouldn’t work :)”
Student A <keeps testing it>: “It doesn’t work”

Student Ed pressing the SAM Button
Student N: “Student Ed it’s not going to do anything yet. It’s not going to do anything!”
Student Ed: “I love pressing this button”

Student N: “It doesn’t work…” <looking for me>
<I join Student N>
Student N: “I’ve added the SAM players, it doesn’t work”
Student A: “It doesn’t work”
Researcher: “Why not?! Why doesn’t it work? OK let’s think about it”
Student N <testing it>: “Surely the sound would have gone off by now, yeah?” <showing my it definitely doesn’t work. Like, this should… wait, what does this mean..?”

Researcher: “Yeah, I don’t think it’s that… let’s think about it, why doesn’t it work? So you press a button..”
Student N: “You press the button, it spits a random number, 1-6 so every time there should be some kind of noise because they’re all the same atm..”
Researcher: “It doesn’t let you test this function somehow…”
Student N: “We tested it already on the other site though”
Researcher <taking over the mouse>
Student A: “Do you need to deploy the code? There’s a button called ‘deploy’”
Researcher: “Yeah, maybe actually, maybe”
<sound going off>
Student N <arms in the air>: “YES!!!”
Student A: “Oh my, oh my GOD”
Researcher <to Student A>: “Good work. Very good thinking!”
Student N: “Yes. we have to get different sounds now”
Researcher <to Student A> : “Is it random?”
Student A <testing it>: “Yeah”
Student N: “Yes…!!!”
Researcher: “Good work.. Now, what do you need now?”
Student N: “The sounds..”
Researcher: “Yeah, I can help you record the different sounds…”
Student N: “Yeah”
Student N keeps testing it, hears a different sound and is very pleased. Boys are gathering around his desk.
Student N: “So how do we get the sounds?”
Researcher: “We can use my phone to record them. We can do them just outside, and I’ll send them over for you to upload”
<Student A and Student N go outside with me to record the numbers>
(from two different groups)
<The rest of the boys keep playing with pressing the Button and hearing the sounds>
<Student N & Student A come back into the room>

Student N: “This is the most complicated SAM I’ve ever done….”
Student N <to Student Ad>: “Look how complicated this is!”

Teacher K: “People are starting to come up with ideas, I’ve got things lines up for 3D printing, who took pictures of their process?”
Student E & Student R + A couple of others: “yes”
Teacher K: “OK, so why didn’t the rest of you?”
Kids: “I forgot. I spent an hour designing... “
Teacher K: “OK, well you can take screenshots as you go, as you are doing it. Next lesson I’d like you to try harder. You’re still not keeping a record of what you’re doing. It’s understandable, because you’re thinking about what you’re doing and what you want to do, but you do need evidence, you do need to have some record.”
Kids: “Isn’t the evidence what we’re doing?”
Teacher K: “No, because you need evidence of changing your mind and the development of your ideas, not just the finished product. How you’re putting things together, how you’ve progressed. Your final product will show something, but it won’t show us the final journey. So you need to start doing that.”

Teacher K: “I think we need a lesson when we just do that, otherwise there will be nothing to show for it.”

Teacher K: “So who’s changed their ideas?”
Student Ew: “Oh massively. I started to design, I wanted to create my own wife, and I did everything apart from the hair, so I found an STL and put it in TinkerCAD..”
Teacher K: “OK, what about you Student N?”
Student N: “Basically at the beginning I was going to do a die roll by a random colour, but then I changed it to a voice ‘move x spaces’”
Teacher K: “And you did it as random, no? How did you do that? Did you use code for that?”
Student N: “Yeah, it’s random using javascript code”
Teacher K: “Fantastic”
Student R: “I’ve got quite a few changes. So instead of money it’s now coins, I was going to do credit cards but it’s now 3D printed coins. I’m going to have a castle as a center-piece, and SAM is going to be more involved now.”
Teacher K: “Why is SAM more involved now?”
Student R: “I needed a few other things working first. There are things that you can only do with SAM Labs.”
Teacher K: “It’s becoming more important because you’re discovering what you can do with it. You’re experimenting and trying things out.”
Teacher K: “So that’s exactly what I mean by your ideas evolving, but that’s not reflected in SeeSaw. The SeeSaw journey should be reflectings all these changes, so when you look back you can see what you’ve done. It’s an important step”

Teacher K: “So tell me practically what you’ve learnt today, any skills you’ve improved?”
Student E: “First of all how to use TinkerCAD, how to use the arrows and to drag things around. I’ve learnt you can change the text from someone else as well.”
Student Ad: “I’ve learnt how to make duplicates in TinkerCAD and change them”
Teacher K: “Nice, again, you’ve learnt how to use the software better. What about SAMs, what have you learnt about SAM?”
A few kids in tandem: “Oh yes, a lot!”
Student E: “I’ve learnt how to covert files in it, and also, you don’t actually need a buzzer to use a pressure plate. I’m using a SAM player instead.”
Student Kr: “I’ve learnt how to import from Thingyverse…”

Teacher K: “Nice. So overall, who feels like their project is moving forward?”
<most boys raise their hand>
Teacher K: “Who doesn’t feel that way?”
Student K & Student L semi-raise their hand.
Teacher K: “OK, that’s OK. Maybe your main idea needs changing. Are you happy / infused with your idea?”
Student K & Student L: “Yeah, I think so..”
Teacher K: “Ok, so what’s the problem? What do we need to change? What can we do to help you move forward?”
Student Ew: “I can help you next week”
Teacher K: “Right, we can all help you figure out what we need to do to help you with your game”

Student Ad: “I don’t think mine has moved forward… I’m not sure, because I don’t know where to start. I’ve got 3D printing, I’ve got pressure pads, I’ve got how my characters move around the board…”
Teacher K: “You’ve got too many things going on. OK. So let’s just focus on one. You need to focus on one thing at a time.”

Student Ed mostly worked on his Tinkercad characters without speaking much.

<Student A watching the SAM inspiration videos Teacher K uploaded in the Technology folder for the boys to watch>
Student A: “I’m doing this, I’m doing SAM”
Student A <taking his headphones off after listening to the SAM videos>: “I have an idea”
Student Ew: “What are you doing?”
Student A: “I’m doing SAM!! Focus on what you’re doing!”
Student Ew: “I don’t know how to do it”
Student A: “You don’t know how to do it? Well I’m not going to help you.”
Teacher Assistant: “How can I help”
Student Ew: “So, I’ve gone to Thingyverse and downloaded this..”
Teacher Assistant: “Right, so you need to download it and unzip it, it’s an archive”

Student L: “Wait, I’ll get SeeSaw to show what I’m actually making” <presumably the whole board prototype reminder>
<working on the characters, looking for characters on Thingyverse, trying to find a Shakespeare character>
Student K: “OMG what am I supposed to doooo? To print or not to print?”
Student K: “I don’t really know what to do”
<when Teacher K comes close, they don’t ask any questions>
Student K: “Student L, look look I’ve got in in TinkerCAD. Student L, do you seriously think this is OK?”
Student L: “Yeah, that’s it”
Student K: “OMG I hate it it’s horrible”
Student L: “It’s good.”

Teacher Assistant comes over: “What are you up to atm?”
<no answer, the boys ignore him>
Student L: “Student K doesn’t like…”
Teacher Assistant asks again: “So what are you actually doing?”
Student K mostly mumbles and avoids an answer
Teacher Assistant: “I think you need to look for an Elizabeth with an ‘i’ as a roman numeral”
Teacher Assistant: “I think the characters you want are not very popular on Thingyverse…”
Teacher Assistant: “Just try queen elizabeth but I’m not sure you’ll find much”
Student K: “Whatever happens I’m not going with this <the previous design>, this is too creepy”
<they keep looking for a Thingyverse queen>
Student K: “I cannot find a queen, I cannot find a queen, I cannot find a queen…..”
<for the last part of the lesson they don’t speak much, Student K continues to click on his laptop, Student L is mostly distracted, and they don’t seem to progress with the game>

<at the end of the lesson once all the boys are out of the room and only Teacher K, Teacher Assistant and I are left>
Teacher K: “One thing I wasn’t happy with was their attitude. They were very different last week. Very calm, very…”
Teacher Assistant: “A bit more enthused, more into it!”
Teacher K: “Yeah!! Yes, yes. Student L is concerning me. All teachers are worried about Student L and doing his work. Student L is kinda of showing off, they want to push a bit more because they won’t blow up. I do find that dynamic (Student K and Student L) very difficult. Neither of them is taking control. Student J is taking control in his, Student Ad is taking control of it, Nick is taking control, etc.”
Teacher K: “How do you think they are coping with it? Are they learning anything?”
Teacher Assistant: “Yes, I think so! The problem is time, but yeah..”
Teacher K: “They don’t have patience to learn something, they just want to go ahead and do it..”
Researcher: “But maybe that’s the whole point of the project, the whole benefit.. They’re not learning/practicing a condensed and controlled specific bit of content, they’re learning how to manage a more unknown task with many options available and different parts to it.”
Teacher K: “I just wish they recorded more, they don’t record much, I don’t understand their reluctance to do it. Is it too much to do it?”
Teacher Assistant: “No, I think it need to be incentivised a bit more, how do we make them want it..”
Teacher K: “It’s very hard work, getting them to want to do them. In a way that’s the whole point of schooling… “
Teacher K: “Well I need something to mark and show something for it”

Student R <coming back to computer with SAM blocks>: “My ideas are: Student E, are you listening?”
Student E: “How are you going to make that move?”
Student R: “It’s not going to move”
Student E: “What is that for then?”
Student R: “Well to move you need to know how many spaces to move around the board..”

Student E: “Or pressure pad”
Student R: “Yeah as you pass Go, a light will go off”
Student E: “Researcher, how many pressure plates did you say we can have each?”
Researcher: “I think you can have as many as you like pretty much… as many as it is feasible..”
Student E: “So say 4, 1,2,3,4 on each corner of the board..”
Researcher: “Yeah, can’t see why not”
Student E: “So when you land on Go you get a light, and when you land on Jail it will say ‘Go to Jail’, etc”
Researcher <bringing over a pressure pad>
Student E: “Can it set off a buzzer?”
Researcher: “Let’s try it”

Student R <talking in parallel to Teacher K and holding the DC motor>
Teacher K: “It’s a great idea Student R, just try it!”

Student E <Researcher walks away but Student E goes to Teacher K>: "Miss, can you link pressure pads to buzzers?"
Note: making sure it WILL work
Teacher K: "Yeah."
Student E: "OK good"

Teacher K <comes over briefly>: "Can I also strongly suggest you look at the inspirational videos?"
Note: Teacher K trying to get people to look at the inspirational videos… but the students are keen to try it and work on their own ideas. Conflict between Teacher K's intention to get the students to get hands-on, try things and test them for themselves… and the thinking time she would like them to put into it BEFORE jumping into it. Also reflected into the comments from the end of the lesson with just her, Teacher Assistant and I.

Researcher <comes back>: "Ok so let's try it"
Student E: "So how will it work"
Researcher: "If you put it like that on the board it will always go off. So you need to use a filter to figure out the pressure at which you want it to be triggered"
Researcher: "you have to try it. I don't know how sensitive it is"

Student E: "Wait, so how do you use a sound?"
Student E: "Oh player sound"
Researcher: "Yes"
Student E: "And then… how do I… and that?"
<Student E seeks constant reassurance he's doing the right thing>
Student E: "And can you get one like that"
Researcher: "Yeah, if you get one, you can change your path here, so you can add your own sound."
Student E: "How would you do that?"
Researcher: "What sound do you want to produce?"
Student E: "You know the Dum dum dummm…"
Researcher: "Try that. Try typing that in and look for that"
Researcher: "So you find it on YouTube and download it.. Look 'Download SAM Labs sound effects'. So here, you find other sounds"
Student E: "Oh yeah"
Student E: "So how would you search for it?"
Researcher: "I don't know.. I reckon just try and type into Google, dum dum dum"
<Student E imitates the sound whilst searching>
Researcher: "there you go"
Student R <managing to get the motor to work>: "Yeey, Student E look, I got it to work"
<his work up to this point is not in SAM, as he didn't name it. Now I've asked him to name it>
<Researcher continues to help Student E upload his sound to the SAM player>

<in the meantime Student R is also working quietly and on his on on SAM, on the dice.>

Teacher K: "So what are you thinking Student R? How will you tell people how many spaces to move on the board?"

Student R: “Ahm… I’m kind of getting into that.. I’ve had this idea… So when you land on or go past the 200, a light would go off like that.”
Teacher K: “Nice, that’s fantastic. But at some point you’re going to think about how your players will move around the board. How will they know how many spaces to move?”
Student R: “That.. that.. I was thinking, maybe a buzzer. So if it was to buzz 2 times, you move twice, so you move as it buzzes.”
Teacher K: “Yeah, yeah, that can work, or if you make it random you can also use the light, how many times the lights flashes that’s ow many spaces you move. If you had a delay on it.. Or you could use the different colours so if it’s red, it’s 2 spaces, if it’s green ,it’s 3 spaces.. Etc. and you could have it randomly generating.”
Student R :”oo… How would you get it randomly?”
Teacher K: “I’m sure there’s a random in here as we’ve said about it. It’s a cycle colours. Because we’ll be cycling round. Put that with the button. Get rid of that. Then somewhere here there’s a random… they did put a random in for us…Ahm, Researcher, I thought that SAM had put a random generator for us? He wants to press a button and the color would generate a colour to move that many spaces…”
Researcher: “Ahm… not sure..”
Researcher: “I think the best way to do it is write some custom code”
Teacher K: “But you can still try it whilst Teacher Assistant looks into that… You can arrange your lights and..”
Student R: “Can I get another light?”
Teacher K: “yes, yes.”
Teacher K: “So if you use it with cycle colors for now..”
Student R <as the light goes off>: “OHH!! Will that not work…”
Teacher K: “yes… but is that random? Or is that in a pattern? We want it to be random”
Student R: “Can I get a bit of paper to write this down?”
31:00
Student R: “Student E, where I am atm, I think I;ve worked out a way to do the dice, with the colors.”
<The are both clearly focused on getting the final thing done.>
Student E: “Wait but you’d have to have loads… you’d have to have 6 colors”
<Student R is sketching on paper>
Teacher K: “Teacher Assistant is working on the code. So when he’s got the code, he’s going to bring it round and give it to you”
Teacher K: “You just figure out if the rest of it will work, test it out…”
Student R: “Yeah, it should work, hopefully…”
Student R: “Student E, press the button. Press the button”
Student E: “Student R, Student R, look, so this is what I’m intending to do. So you know the sounds dum dum dum, so when you press it, it will say dum dum dum.”
Student R: “How are you doing this?”
Student E: “I’m just converting it”
Student R: “I need another light”
Student R: “Student F Student F, look at this… .clever!!”
Student R: “Student F, Student F, look disco party!!! Disco partyyyyyy”
Student R: “Disco PARTY!!! I am a GENIUS”
Student R: “URGH it’s not working!! Please work! Why aren’t you working?!”
<gets the buzzer to work and keeps playing with the buzzer>
<Student R takes a photo presumably to upload to SeeSaw of his SAM graph>

Researcher: “Nice, good work. And we’ve got a bit of code for the random number generator, if you want it.”
Student R <hesitating>: “Ahm… “
Researcher: “Are you going to do the random number generator or not?”
Student R: “I am going to do it, but I’m not going to do it NOW..”
<hesitating to fail with the code, to complicate things once he’s got them working… sounds complicated, doesn’t know how exactly he would go about introducing it… so prefers not to do it>
Student R: “Yeah. Does SAM save automatically? “
Researcher: “yes”

Student E: “This is so hard! How do you… ? Researcher, do you know how to do 3D printing?”
<he had only spent a few seconds on it. Got stuck and immediately reached out for help.. He does it repeatedly throughout the lesson, a few times till now already>

Student R: “Student E, how do you search? Student E, how do you search?”
<Student E doesn’t answer. Student R doesn’t get an answer for a while, keeps asking around, but also keeps trying. Eventually I come by and say that he can’t search in TinkerCAD, he has to search in Thingyverse. Student R gets it done immediately.>

Student F: “Remote control, just make it somehow, and then have these wires, and things are connected to the wires and as you move around…”
Student Ad: “I will have this vibrator, that dictates how many moves you make..”
Teacher Assistant: “So… how is that going to work..?”
Student Ad: “The vibrations move it”
Teacher Assistant: “So, the only thing with that, if the vibrations are moving it, the vibration itself is not going to push it reliably in any one direction. Think about your phone, when it vibrates it moves on the table but not necessarily in controlled direction. Have you got any other ideas?”
Student Ad: “Yeah..”
Teacher Assistant: “Ahhhmmm… so how is it actually going to move? Once you press the button what’s that actually doing to make the piece move?”
Teacher Assistant: “My concern is that it’s a great idea but it’s a bit ambitious in the time you’ve got. I can’t think of an easy way to make a character move. You can do it, but the character ends up big and the board would need to be huge. I can’t think of a feasible way to make the characters move automatically. It’s a bit tricky. You can think of other more individual elements to do with SAM, but moving characters automatically will be hard.”

Student F: “I want to do the 3D printing”
Student Ad: “Yeah, let’s do it”
Student F: “Can I log in?”
<they work with Teacher K and Student F to share the TinkerCAD project>
<Student Ad goes and chooses SAM blocks. Picks up a DC motor with a wheel on it for the spinner, but doesn’t do much with it. Moves on to talk to Student Ew about 3D printing hair and his coins for characters.>

Student F: “I want to do ICT every year. It’s really fun.”

Lesson 6 - 16th Oct

41:00ish
Teacher K: “I’ve learnt something in the last lesson. I’ve learnt that if you print in plain color it goes much easier and quicker, so I’ll print all the first version pieces in plain color, and then the second version in color. I don’t want to be wasting the color material, and takes quite a lot longer. So I’ve learnt this, I’ve adapted my ideas and my thinking about how I will 3D print your pieces, because the first version might not work.”

53:00ish
Teacher K: “Right, can you boys stop for a minute. Can you please spend 10 minutes in SeeSaw uploading where you’re at atm, what’s working and what’s not. When you’re on SeeSaw, you’re telling me what you’ve been doing but you’re also telling me what you’ve changed. So if you’ve made some changes or found a way of doing it successfully, you need to tell me. So you really need to explain to me where you’ve come from. What’s changed and how you’ve developed it. So it can’t just be one sentence, that won’t be enough.”

Student R: “I’m just thinking, using this <SAM>, I know we’ve got the music,...”
<Student R gets the SAM components from previous lessons connected again and gets the buzzer going>

1:05ish
Teacher K: “Student Ad you worked on the box..”
Teacher K: “Student L, so you’ve changed Henry to make it bigger. Why did you make it bigger?”
Student L: “Well.. I think it was just too small..”
Teacher K: “Ahm, yeah, but why did you reach the conclusion it was too small? Did it break?”
Student L: “Ah yeah it broke”
Teacher K: “So it was too small, too fragile. So you had to make it stronger, bigger. Do you still have the broken one? You can put up a picture of it and explain.”
Student L: “Yeah”
<Reluctant to talk about the broken Henry, as a failure>
<Teacher K goes through every SeeSaw entry and discussed the specific changes that emerge from each entry, comments on how the entries can be improved to be more informative of the process>
Teacher K: “If you don’t record your changes along the way, how are you going to know looking back what you’ve changed?”
<Teacher K trying to incentivise students to record their changes, and explain why their record is worthwhile…. But not doing a very good job>
<The students record what they’ve DONE, not why they’ve done it, what problem / challenge they were overcoming in doing it>

Student F: “I want to work on the SAMs”
Student F: “Why don’t I just go like this? <opens SAM Education”

Student Ad: “Yes”
...
Student Ad: “Hey, I thought you were doing SAMs”
Student F: “I am. But I need SAMs. I need the blocks”
Student Ad: “Well you can go get them”
<Student F connects a button to the DCMotor and keeps playing with the wheel attached to the motor as a shaver..>

<Student F making silly noises and playing around with the ‘shaver’>
Student Ad: “Student F, be sensible...I know you’re not good at that stuff <SAM>, but just try>”
<Student Ad walks to get a SAM blocks to size it up, Student Ad takes over his computer to continue in TinkerCAD working on the box that will contain the SAM blocks>
Student Ad: “3,5 by 3 y 2”
Student F: “I don’t know what you mean by 3 by 2 by 2…”
<Teacher K comes overs and takes over and resizes the box. She mostly addresses Student Ad as she adapts the box. She walks away>
Student Ad: “Student F, do you understand?“
Student F: “No” <getting visibly bored>
<Student Ad tries to explain but ends up taking back over and Student F wanders aimlessly in the classroom>
<The SeeSaw entries from Student Ad are entered only after Teacher K challenges them on ways in which he didn’t explain his changes and why he did whatever he did.>

Student J:

Student J: “I feel like a test subject. <after Teacher K’s talk about printing in plain color first>. Which I am”
Student J: “How would I do a spinner with SAMs?”
Student J: “I’m loading up SAM!”
<Student J goes to pick up SAMs>

Student J: “Watch this watch this!” <connecting a button to the player, putting his headphones on and listening to the different possible output sounds>
Student Kr: “How do you make it output your voice like ‘move 2 spaces?’”
Student J: “I don’t know”
Student Kr: “But you’re doing SAMs, you’re supposed to know about SAM..”
Student J: “Yeah but we haven’t done that bit, look at the projects we’ve done: buggy car tag, twitter, etc…”

Student Kr <working on the spinner>: “I find this very confusing”
Teacher Assistant: “What do you find confusing?”
Student Kr: “This is very confusing”
Teacher Assistant: “What exactly do you find confusing, what are you trying to achieve?”
Student Kr: “So how does this stop on 3? How do I make it 3 spaces?”

Teacher Assistant: “Well that’s your decision, however many parts you want to split the spinner in. It can be 3, 4, 6, that’s a decision between you to to make”
Student Kr: “There’s only 10 squares.”
Teacher Assistant: “So each player can only move 10 squares and they end the game? So really 3 is quite a lot, if they hit 3 three times they can finish the game in 3 goes. So really you want max 2 spaces or more options. How many questions do you have in your game?”
Student J: “60”

Student Kr: “Why are you using a buzzer when it’s nothing related to the game?”
Student J: “I’m testing it”
Student J: “Can you hear the buzzer?”
<Student J keeps testing the buzzer by hiding it in different places, to check if it’s still audible>
Student J: “I’m actually confused as to how I use a ‘Delay’. Cause I know there is a ‘Delay’ block but …”
Student J: “YES! Look at this” <the delay works>
Student J: “I’m a genius”
<Student J gets distracted by the iOS upgrade and the new iPad apps, and turns to the other boys to discuss them. Ignores SAM. So probably didn’t test very much in this session>

Teacher K: “Student L, your first 3D printed Henry broke because it was too thin at the base. What I want you to do is take a picture of the broken one and record it as a first attempt, and tell me how you think you can improve it.”
Student L: “Make it bigger”
Teacher K: “Yes, thinker base, bigger piece.. But I want you to record it as a first attempt, tell me what the problem is and how you’re going to fix it, and we’ll see the difference between versions.”

Student K: “OK fine, I’ll start with SAM”
Student K: “How am I supposed to start SAM?”
<Student K hadn’t actually worked in SAM at all, unlike all other boys, and yet he didn’t hesitate to start the work in it>
Student K: “So what blocks do we need to use?” <keeps his hand up for ages trying to get someone’s attention for an answer on how to start with SAM. Eventually Teacher Assistant comes over>
Student K: “Ahm, can I get some SAM blocks?”
Teacher Assistant: “Oh, yes, go help yourself”
Student K: “OK… so what is this?” <connects it and discovers it’s a light sensor>
Student K: “OMG this is a light sensor. OK ..how do I get rid of it..?”
Student K: “Student L, Student L, Student L what am I supposed to do with this SAM?!? I need some help with SAM.” <now that he’s got it open, and a couple of blocks connected, he realises he doesn’t know how to use it or has any idea of what to build>
Student K: “I have no idea”
Student K: “I’m not stupid. How do I do it? I am becoming stupid, I am becoming stupid, how do I do it? I am becoming stupid, somebody help me.” <goes over to Student J and asks ‘What block is that?’. Goes and picks a buzzer up. Now the virtual one he had in the SAM graph is now physical”

Student K <connecting the button>: "Now I've got it"
<Student K getting the buzzer to work and playing with the notes, very pleased>: "So stupid…" <but clearly pleased with what his achieved even if he thinks its simple. Keeps testing it>
Student L: "How do we change it to something else?"
Student K: "Not sure. I don't know, I'm not sure. I have no idea what to do. What are we supposed to do with SAM?!?"

Student K: "I think I need help with SAMs, I'll need help a little bit"
Teacher K: "OK, with SAM. What are you trying to do?"
Teacher K: "OK so you've already got this, so when you press it what happens?"
<Teacher K interestingly takes a seat at Student K's laptop and leaves Student K standing behind her… shift of control dynamic - tension."
Teacher K: "OK, so the buzzer goes off. So do you want a buzzer or do you want a different kind of sound?"
Student K: "Different sound"
Teacher K: "And have you paired that?"
Student K: "Yes. It's paired"
Teacher K: "Ah OK. So, it's not a buzzer then, it's a player. So first thing to do is … let's see what you've got atm… is unplug the headphones."
Student K <putting his hands over his face>: "Argh, that's WHY…"
Teacher K: "OK, yeah? Do you need any more help now or was that the problem?"
Student K: "No, that was the problem"

Student K: "Student L, listen to this <the player sounds>"
Student L: "Do the scream, do the scream"
Student K: "OK, so I just need to make them like … 4. I just need to make it 4"
Student K: "OK so we need 1 button, 2 buttons, 3 buttons… cause I just want it to be like.."
Student K: <this whole session is lost on SAM because the project was unnamed :(>

Student L: "YES, Student L, Student L look. This is so cool. Student L look this is so cool <shows all the connected buttons colored.>"
<Student L puts his headphones on and they test the buttons>

Teacher K: "OK, so you're going to do what?"
Student K: "So, for each player there's going to be a different sound.."
Teacher K: "OK, so… are you wanting different sounds in it? Do you want each player to have its individual sound?"
Student K: "Yeah.. so that one is Scream, the other is the Doorbell, etc.."
Teacher K: "OK, so they're already different sounds for different players. So what's the problem?"
<again, sits down at Student K's desk and takes control of his computer, leaving Student K behind her>
<Teacher K tests each button. The three already there work.>
Teacher K: "OK, go get another button"
Teacher K: "Also, can I just say, are these buttons for each player? You almost need a box around it of different color. So each player has a different button in a box of a different color.

And your players have their own box and button. And needs to be slightly bigger on the outside than the inside..” <Teacher K leaves>
Student K: “OK, another button, in SAMs. It will work”
Student K: “Maybe it’s not that bad.”

Student K: “Yeah, let’s drop Shakespeare, 3 players…” <pointing at the SAM with the 3 buttons & players>

Student A: “Nick, you’re copying me..”
Student N: “But you copied me in the first place”
Student A: “Yeah but now you’re going to have to copy me…” <in the setup of their voices>
<Student A and Student N receiving the recorded voice for numbering from Teacher K, downloading them,
Student A: “Why do you not seem to work?”
Student N: “Student A how do you add them to SAM?”
Student A: “You have to go into the player… how does it work for you but not for me? Does yours work?
Student N: “Yes. Wait, are they the same?”
Student A: “Well the code is identical. So why doesn’t mine work?”
Student N: “Wait is the button paired?”
Student A: “It’s not registering”
Student N: “Connect it again. Click the button and connect it.”
<the SAM players start working with the recorded voice ‘Move 5 spaces’>
Student N: “How do you add them, how do you add them?”
<Student A takes over and uploads the voice to the player>

<Student K comes over and takes a look>
Student K: “wait how did you do..? Ohhhh…. <looking at the graph> now I understand”
Student N: “Wait, do you understand this?? <opens the code>
Student K: “No” <walks away>
Student N: “Exactly”

Student N: “Yes Student A!! This is getting somewhere”
Student A: “Wow, wait, this is wrong, very wrong…”
Student A: “I’ve messed it up”
<fixes it and it goes back to working>
<Student A takes a photo to upload to SeeSaw - proactively!>
Student A: “Nick, we’ve done it!!”
<they keep trying it, activating it, nothing added for the SAM system. Once the dice is achieved, they take a break. They don’t do anything else. They feel like they’ve got something significant to show for the day, so despite not actually doing much on it on that actual day, they don’t progress in any other way. On this day, they didn’t change anything, they didn’t test anything, they didn’t adapt anything… but they’ve got a lot to show and upload in SeeSaw>

Student E: “So have you got the same thing?”
Student N: “Yeah, we’ve both got exactly the same stuff”
Student E: “So you did this together?”

Student N: “Yeah”
Student E: “Did you send each other the stuff?”
Student N: “Yeah”
Student E: “Yeah but that noise is so annoying … move 5 spaces…”
<other boys come round and test it and check it out>

Lesson 8 - 30th October

Only Student Kr recorded. The rest were told not to: “No, today you don’t need to record. We didn’t know we were going to have this lesson so we’ll just go without the recordings.” <extra distraction, extra scrutiny?>

<During this lesson, Student J worked with the SAM blocks. Testing buzzers, players as heard in the background. I think Student K did some SAM that lesson too, Student A a bit.. Mostly just rearranging his dice in the same way as it was before. No view of Student E/Student R/Student F/Student Ad. Student K is experimenting with a spinner by the end of the lesson - a DCMotor with a wheel on it>
Student J: “I’m trying to get these sound effects done with SAM, but I can’t find…”
Teacher K: “I thought I’d just put on 3 of them… <walks away with headphones in her hand>”

Lesson 9 - 6th November

Teacher K: “Looking at SeeSaw, it’s interesting to see what some of you have been doing. However, some of you are just putting little bits that don’t say a lot about it. They say a bit, but it’s not telling me a huge amount about what’s actually going on. If you think about coming to mark this at the end, if you imagine marking today, I won’t have much to go by. We’d have to fill in a lot of the gaps, because we’re here with you. Also, for you, when you get to the end of the project, you’re going to be a lot more interested if you’ve put more information. So today, we’re going to start with 10min in SeeSaw, with these questions:

- Did planning the way your player moves, (as in the dice), and getting feedback and adapting you ideas help you refine your overall game plan?

How many people have actually nailed down the way their players will be moving around the board?”
Student K: “I’m making a spinner”
Teacher K: “Nice, so I know you are doing the randomiser, Student E is doing it by random colors, so most of you have it. Could you write that down and take photos if you have it. And secondly:

- Did you have to solve a problem to make your design work? If so, how?

So you’ve got 10 min to go to SeeSaw and then start the lesson. We’re going to put up a checklist to make sure everyone stays on track”
<interesting change on dynamic … a lot looser explanations of why the students should update SeeSaw and how…, vague questions…, and the mention of the checklist ensuring students stay on track is also interesting..>

<The checklist is more representative of what Teacher K wants an update on, rather than where they students are and what they can focus on… they are further ahead>

Teacher K: "OK, so most of you are done with SeeSaw, so it will be interesting to have a look and check what you've uploaded. In the meantime, this is your checklist: 1) have you designed your players? Do you have a complete design for all players in your game? Are they now being 3D printed? Are you 3D printing them in color or are you painting them? 2) Have you thought of a way for the players to move around the board instead of using a traditional dice, and have you finished designing it, and is it working?
This is what today is all about, getting these two parts done to move on to the overall board design and add more intelligence to the board mechanics"
<reverts back to the final output 'checklist' as a way of keeping students 'on track'>

Student K: "I'm going to stick to SAM"

Student K: "Oh wait, OMG this is going to be the best randomiser…<I think he found the delay> I'm going to put a delay in it."
Student K: "Student L, Student L, this is it. Spinner buzzer, buzzer, spinner…"
<They work together a bit more on a 3D box to hold the DCMotor, working on the size of the box… and not much else. The 'checklist is done… they have their characters and spinner so… not much else to do on the day. They mostly mess about, singing to themselves. Student K keeps working at his computer, but unclear on what - don't think it's SAM as he's not testing anything physically.>
<Student L then takes Student K's headphones and tests the SAM work Student K did. He makes some changes on Student K's machine and tests again>
Student L: "Let's test this. Student K, let's test this. That is… no we don't want it like this."
<Student K changes something else>
Student K: "OK how about now?"
Student L: "Ok so how can we like… do all of them?"
Student K: "Well there will be 3 of them"
Student L: "OK, so should we get some more SAMs?"
Student K: "Yeah"

<Teacher K comes over and sits in Student L's seat and takes control of the computers>
Student K: "We need more buttons for the buzzers"
Teacher K: "OK. And how is this <the spinner DCMotor> going to stand up?"
Student K: "We've made a 3D box"
Teacher K: "Oh, super!" <leaves>
<Student L brings over more buttons, they connect them, and they take it in turns to take the headphones and test the buzzers (or probably players)>

<Student A opens up SAM Space Education>

<Student A works in TinkerCAD on a house that looks like a museum, Student Ew also refining things in TinkerCAD. They chat briefly every now and again about the printing - how long it will take, what color, what size, etc.>

Student Ad: “I was thinking of a horse and cart to move around the board… but it might be too big. I was also thinking of using pressure pads..”
Researcher: “yeah.. Horse and cart might be too big.. “
<moving on to 3D print a throne as a piece for the middle of the board”
Student Ad: “So I was thinking of using pressure pad in random places on the board, to reveal a code. And each pressure pad will reveal one letter of the code. And to finish you have to have the code”
<they continue working on the 3D printed throne>

Student F: “Done.”
Student Ad: “No, it doesn’t work”
Student F: “Pfff… I’m going try it. I’m going to try!”
<Student F is happy to attempt it even if it’s not sure it will work>
Student F: “I’m SO good at this Student Ad, look!”

Student R: “Mrs K, so actually, I was thinking…”
<Doesn’t continue. Neither of them work with SAM, they are both working on their 3D printing for most of the lesson>

Teacher K: “How many people feel they’ve made progress in this lesson?”
<most students raise their hand>
Teacher K: “How many people feel they are able to tick off their checklist?”
<most students raise their hand>

Lesson 10 - 13th November

Researcher: “How are you going to use SAM for players to move around the board?”
Student J: “Well, there’s not going to be much SAM, but I’m going to have a spinner, and I’m going to cut out a piece at the end of the pizza box and put a light sensor in it. So when a player lands on it, it will cover the sensor with the base. So when the player lands on it, it will make it like do something.”
Researcher: “That sounds good, but I wonder if there’s more you can do”
Student J: “It’s hard to sort of think about it..Cause you have an idea and then.. You think about it too much… Like, I had an idea that you can sort of, use SAM for counting, but then you have to have the computer involved so…”
Researcher: “Yes, but for the SAMs to work you need to be next to the computer anyway don’t you..?”
Student J: “Oh yeah…”
Student J: “Cause I was thinking if it was something but then you could only use it in classroom, you couldn’t use it outside the classroom..”
Researcher: “So what were you thinking with the counting?”
Student J: “So I was thinking to do the counting in the app, so if you click a button, it would do something, but..it’s hard for the computer to tell, if you click the button, is it good or bad.. You can have true for every single one of them, but then you’d have the false ..”
<They work on the pizza box design for a little while and the rules..>

Student J: “Actually I’m going to work on the SAMs now”
Student J: “OK I’ve got the spinner!”
Student J: ”We need to make it random, but I don’t know how to do that” <but then starts introducing Holds>
<I go over and remind Student J to save the project… which means nothing is saved from this session from his SAM :(>

Student J: “I’m not sure, it doesn’t do it the same amount of times every time so I’m not sure..”<talking about the spinner to me> “It goes here, and if you click it again it might go to the same one..”
Researcher: “Does it actually spin..?”
Student J: “It does but it takes a bit of time. Look 3,2,1…and the next. Because I’ve got a delay here..”
Researcher: “So do you want it with a delay? You have to wait 4 seconds before you get to spin...”
Student J: “I don’t really, but I’m not sure how not to do that…I just kind of took it as a guess”
Researcher: “Well what exactly do you want to achieve?”
Student J: “So like it will spin for a certain amount of time .. “
Researcher: “In that case you might want to use a Hold instead..”
Researcher: “3 seconds is actually quite long but that’s fine..”
Student J: “Because, will it go to ones of these..?”
Researcher: “Yeah”
Student J: “Thank you. We’ve got it working. It’s random” <big smile>

Student K: “I’ve done it”
Student L: “Oh, you’ve done it. So what’s going on? It buzzes? And ...”
Student K: “After you press, 2 seconds later it starts spinning, and it holds for 5 seconds, so it’s random.”
Student L: “I can also get some .. like lights, and..” <they go and get more blocks and paper>
Student L: “OK so let’s say you’ve got a buzzer here, and they move… 2,3, let’s say 4 spaces..”
Student K: “I can have a light sensor, and when it’s 0, just like SAM…”
Student L: “Wait, what?”
Student K: “So if you land on it, so if it’s a light sensor and it’s 0..”
Student L: “It lights up that amount of times?”
Student K: “yeah… no no no, wait”
Student L: “Wait, so if you get it right, you move forward a random number of times, say 4..”
Student K: “Yeah, and with a light sensor, you land on it, and you get asked questions, and I’ll show you”
Student K: “I’m going to do SAMs…” <singing>
<Student L works on the cardboard with numbers for the spinner>
Student L: “Yey it works! I’m actually so happy, I’ve got a spinner”

Student K: “Student L, I’ve done it! I’ve done it! Let me show you”
Student L: “Let’s see”
Student K: “So, if this is a piece of the game, and put a piece of paper on it…”
Student L: “Should I go get the pieces?”

Student K: “Lacklan, look look.” <Student K shows physically how a player moves on the board, gets to a space with a light sensor on it, and another light goes off because the light sensor is covered so receives no light (=0)>
Student L <excited>: “OH.. Wait, so what does that mean, when it flashes?”
Student K <starts laughing>: “Then ahm…. I don’t know hahahahah the light flashes”
Student L: “Yeah but what actually happens?!”
Student K: “I don’t know..!!”
Student L: “You’ve just done it for the sake of it”
Student L: “Should I do it so if it flashes, you move forward two?”
Student L: “Or, if it flashes blue, you spin the spinner, and that’s how many you move”
<I think Student K didn’t have the project saved, so I don’t think I have his experiments from today>

Student K: “OMG wait, I’ve just thought of the best thing ever. I’m changing direction.”

Student K: “OK now press it, see what happens” <nothing happens>
Student K: “What?! Delay, hold, switch direction… What does that do?”
Student L: “Try it again with that”
Student K: “Switch direction?”
Student K: “Oh, OMG, wait, I’ve got it completely wrong…”
<they stop the lesson>

Student A: “Today I’m going to mess around in SAM Labs education…”
<THIS is what we want!!!>
Student A: “Yeah… I can do the beheading centre!!”

Researcher: “What are you going to do when the players land on something?”
Student A: “After 5 seconds… I can make it shorter, and then it will output a color, and then should we make like.. Cards? With questions. Whether it’s red, green or blue, it’s a red card, or gree/blue card..”
Researcher: “And will it be random?”
Student A: “No, it’s not. I don’t it to. So they know what’s coming next.”

Student A: “I’ve figured it out! I DID it! Random.”
Student N: “Yeah, didn’t we already do that before?”
Student A: “Yeah, I copied what we had before, used that and… it worked”
<no one is listening, he’s mostly speaking to himself, hoping Student Ew, Student N will listen>

Student A: “I used the code for the dice, I put it in this, and then I set it to the max number is 30”
Teacher K: “So what’s the goal?”
Student A: “So if you land, you pick a card of the color that you get given…”
Teacher K: “So how will you know you’ve landed on it?”
<Student A simulates a character landing on the button>
Teacher K: “Right, would a pressure pad have been better?”
Student A: “Are there pressure pads?”
Teacher K: “Look. Or.. light sensor. Either outside or inside the box”

<Student A starts testing the pressure pad>

Student N: “Hey Student A, what’s the idea of this?”
Student A: “If you … “
Student A: “I tried putting Henry on the pressure pad and it didn’t..”
Teacher K: “What proximity block are you using?”
Teacher K: “Right, so when would they get it?”
Student A: “Get what? So it’s random, so the light goes off..”
Teacher K: “Well, it seems to be going off when you do that… Researcher has helped you with that, you can ask her to come and have a look”
Teacher K: “Researcher is going to come and have a look. Cause you want it to go off when it’s there, not there..”
Student A: “I put the filter in, so if it’s 95 or over..”
Teacher K: “So you want it every time it gets to the square”
Teacher K: “What he wants is, he wants the light to go off randomly. He used to use a button, but he wants to now use a proximity. When he gets to the square, we want it to do a random color. At the moment, it starts generating too far away. If this is his square, it’s when it’s too far away.”
Researcher: “Oh you do have a filter”
Student A: “Yeah”
Researcher: “It’s already quite sensitive. So it’s already set for 95 - 100, you see, even when it’s 65 it still turns on. I think it might be that… there’s a backlog. Do you see what I mean? It’s cathing up. If you wait for the light to stop… and now, if you try to do it.”
Researcher: “OK, now it’s not doing it…”
Researcher: “But that doesn’t make sense. Why did it not come on then?”
Researcher: “Hm….Why do you… ohh you want to put the random colouring in there”
Student A: “I put the random coloring and the filter..”
Researcher :”Oh, I see. Now it’s stopped. Where is it gone?”
Researcher: “OK look, so now it’s not changing…”
Researcher: “I wonder, can we just try to just have the filter. I wonder if that’s confusing it a little bit. Can you try it just with the proximity, the filter and the light?”
Student A: “OK”
Researcher: “OK, let’s try it now. That is looking better… but now it doesn’t”
Student A: “But now it doesn’t…”
Student A: “Because once I’ve done it, I kind of wanted it to .. ”
Researcher: “Oh ok… and what’s a block you can use for that? Yes, try that, in the simpler test here”
Student A: “Cause I tried that before, and it waits 2 seconds and then..”
Researcher: “OK, so you need a Hold then. That’s set to 1 sec, you chan change it if you want”
Student A: “That’s weird.”
Researcher: “Yeah, that’s really weird. That’s definitely a bug. I wonder if it’s the Hold that’s blocking it”
Researcher: “I think there’s two options… no hold or…”
Student A: “But I need to get it random.. I tried putting each colour and when I press the button it would just do ..”
Researcher: “Yeah… I see. SO, let’s see if we can fix this one first…”
Researcher: “What does the Switch do?”

Researcher: “What’s that white thing?”
Researcher: “It’s definitely a bug, because it definitely shouldn’t take the brightness down… I think you’ll have to test it out a bit more”
Researcher: “Are you going to be in the code club?”
Student A: “Yeah”
Researcher: “We can maybe work a bit more on it in the code club”

Student N: “Do you have any actual idea what you’re doing? Actually?”
Student A: “Yeah, I do!”
<Student N is clearly less willing to test than Student A, and doubts Student A’s experimentation efforts>

Student N: “Are you going to have questions? True and False? How many?”
Student Ed: “Yeah. I don’t know. But yeah you can starting working on that. True and False.”

Researcher: “So what SAMs have you got going?”
Student E: “So, I’ve got the color randomiser... I’m going to do the 4 pressure pads in the 4 sections, in the corners of the board…just one second, let me open SAM.”
<I walk away as Teacher K speaks to me>
Student E: “OK Student R, let’s do SAMs. Bye bye 3D printing. Student R, how is the randomiser?”
Teacher K: “OK, what are you going to do? When you land on the square, what’s going to happen?”
Student E: “So I’ve got 4 pressure pads in the corner with sounds, I have Dum Dum Dum..”
Student E: “OK so I need a SAM player” <turns around to grab a physical block.. I think he picks up a buzzer>
Student R: “Now I need a happy tune… if I get the 200 coins”
Student E: “OK so now if I get a connector…”
Student E: “So how do you do it a second time with a happy tune? So if you land on the pressure pad the first time, you get DUm DUm DUm, then happy tune”
Researcher: “So you need two sounds? You want to do it twice?”
Student E: “Why doesn’t it work?!”
Researcher: “Maybe put a filter in between to see what value comes out of the pressure pad?”
Student E: “It still doesn’t work. Could it be the actual pressure pad?”
Researcher: “Try adding a log to capture the output..”
Student R: “I think it’s to do with the actual pressure pad itself..”
Researcher: “Let’s change it..”
Student E: “It works”
Researcher: “So you need to filter the value of the pressure pad.. The button is an on/off thing. The pressure is 1 to 100. So you need to specify above what value you want it to activate”
Student E: “OK so what do I set the filter to?”
Student E: “It needs to stay for longer. How do I do this?”
Researcher: “I think you need a hold for that..”
Student E: “So what do I do with this? Where do I put it?”
Researcher: “Well, where do you think…”
Student E: “Oh wait, I think I’ve got it. Is it here?”

Researcher: "Try it"
Student E: "Yeah.. I'll set it to 5 seconds. And wait, I also need a filter and set it to .. where would this go?"
Student E: "Is this how it's connected?"
Researcher: "Ahm… well, first of all, it needs to be next to the pressure pad.. And then…, what are you going to do with the filter?"
Student E: "I want it so that when there's a certain amount of pressure, then it sets it off"
Researcher: "So between like, maybe when it's in the first 40 to get triggered?"
Student E: "No wait it needs to be closer to that.. Because look <simulates a player>"
Researcher: "But you might as well put it from 0 to 100 since you want it to work with any pressure.."
Student E: "But I need it longer"
Researcher: "OK, the Hold doesn't work cause you've got too many connections. You've got the pressure pad going almost directly to the player. Do you need that?"
Student E: "No" <removes the direct connection, tests, and it works>
Researcher: "And now it's holding it!"
<big smile on Student E's face>
Student E: "Will it work when I do this?"
Researcher: "Well, you'll have to try it out. Maybe you need to raise the pressure pad bit on the board. You have to try a few different ways."
Student E: "What would I use to try it? Would I use this? <a piece of paper>"
Researcher: "So you might need to adapt and try a few different options, with without the board, the filter value, etc."
Student E: "SO will I need to change this?" <pointing specifically at the SAM graph>
Researcher: "I don't know, you need to test it out and figure it out"
<Student E is reluctant to try anything with an uncertain result, keeps double checking with someone else - me, Teacher K, Student R>
Student E: "I need to get another sound"
<goes back to something familiar he knows her can do and how to do>

Student Ad: "I'm doing SAMs for this <holding the spinner>"
Student Ad: "I need to control the speed"
Student F: "Should I use this? <another block>"?
Student Ad: "No I can control it using this"
Student F: "Let's just see, let's just see.." <tests it in SAM>
Student Ad: "OMG you don't actually realise how <*fucked*>???? this is. How many times have I got 1?"
Student R: "Why don't you make them do it behind their backs?"
Student Ad: "OK, that's high speed, and that's low speed"
Student F: "No but you can still time it."
Student Ad: "Yeah but it would be harder to time with a slider wouldn't it? The time it takes to go down"
Student F: "No but you can still actually time it with that"
Student Ad: "Try and get six. I can feel it vibrating"
Student F: "Tell me when it starts moving"
Student Ad: "No not moving. Now, it moves, it moves. Now not moving"
Student F: "At 40. It's at 40 when it starts moving <on the slider>"
Student R: "Can I see how your Slider works?"

Student F: “Yes”
<they keep testing it>
Student Ad: “You can’t count to 3”
<they keep testing it by Student Ad spinning and Student F walking however many steps the spinner sais around the classroom>
<they test physically more than most>
Student F: “Should we get the box to test it?”
Student Ad: “It’s done. I’ve done it. I’ve only gone and done it!!!”
<Student F is more open to the trial-and-error process, less focused on the end result. Student Ad is the opposite>

Teacher K: “Student F, what are you doing atm?”
Student F: “I was going to do something with the board…”
Teacher K: “Why don’t you work with the SAMs? What’s going to happen when the players land on the squares?”
Student F: “It’s going to say ‘You’re player 1, go’ or something like that..”
Teacher K: “OK, well pick up some SAMs and start working on that”

Student F: “I was thinking, I could use these <pressure pads>, and put them on the board, and if someone lands on it..”

Student F: “Are you SURE? Are you sure sure sure? Are you SURE?”
Student Ad: “Leap of faith. Leap of faith.”
Student F: “Are you SURE?”
Student Ad: “This is a design project, first time we can try anything, trust me”

<Teacher K adds a Hold onto their SAM graph to prevent people from cheating. She did it herself entirely, sitting at their desk>
Student Ad: “Genius, perfect. Now we can set the delay to 3 seconds”
Student F: “Put it for..”
Student Ad: “wait, we’ll put it on for 99 hours, 99 minutes.. 9 seconds… haha”
<the spinner keeps going>
Student Ad: “We’ve got it on for 4 hours”
Student F: “Now put it to 4 seconds”
Student Ad: “4?”
Student F: “2. No 3, 3. Set it to 3”

Teacher K: “take videos or screenshots of what you’ve got”
Student Ad: “can we keep our SAMs?”
Teacher K: “No, you’re going to work in SeeSaw now”
Student Ad: “But we’re doing SAM..”
Teacher K: “Oh you want to video it, OK”
<only now I pass by and tell them to name the project.. So their tests are totally unrecorded :(but they didn’t actually do much in SAM in terms of experiments>

Student Ad (SeeSaw video): “This is my spinner that is controlled by a motor and a button and has a a hold on it to prevent anyone from cheating. You hold it for 3 second. I’ve also done a brief <test I think> on paper, so that we just knew it worked, and we used this crap spinner to know how it will work. And this is the actual one in action, so I don't hold it, you just press it and it lands on a number so it prevents cheating. I've also got the box glued to the bottom so that I can take the motor out. I've got the motor at the top."

Lesson 11 - 20th November

<this lesson the SAM Google login didn't work. So the students created temporary accounts with their email addresses (on this day specifically), so their data wouldn't be in their normal accounts… if any data was saved at all from that day>

Teacher K: "I'd like you all to watch the video on iterative design, and then we'll carry on with the lesson"

Student Ad (SeeSaw video): "This lesson I've started doing some measuring for the positioning of the place. I've also like, superglued that down. In the last lesson as you saw in the video I just glued it and it flopped, so now I'm trying it with superglue."

Student F: "I'll have the question on the board, written ON the board"
Student F: "Can you recording using the Buzzer?"
Teacher K: "No, you need the Sound Player"
Student Ad: "Sounds player, That's it, I got it wrong, sound player"

Student E: "Student R, do you know how we get a random color?"
Student R: "Researcher has got the random code"
Student E: "Researcher, I'm a bit stuck. So first of all, there's just 3 colors here. Can I change that to get more colors in the RGB light?"
Researcher: "Yes, there is a color software block."
Student E: "This one? Like that?"
Researcher: "Oh so you want more than three colors… oh I see. I'm not sure.. Try switching them around, color, then…"
Student E: "What it does it just switches color. Which is what we want, but we also want it to be random. I need 6 colors."
Researcher: "In that case, you can't use the RGB. You can only use the color, and choose your color here, one of the 6 colors, and have 6 different colors going in and then randomising them"
Student E: "Wait, so, we join them up .."
Researcher: "That's what you need to do, because the RGB will only ever have 3 colors"
<he keeps trying things in SAM>

Student E: "Researcher, look. What it does is, it changes but it does it quickly. So we need to do the time don't we?"
Researcher: "So you need to think about it a bit more about how you want it to behave"
Student E: "So I want it to be just one color, that when you press it, it will go off as a random color, but it won't suddenly randomly go off like that"
Researcher: "OK. so you want for it to hold the color right?"
Student E: " So I need 6 to 8s… Actually I need one more"

Researcher: “That’s really weird though what is it doing? Cause it is keeping it on just one color…”
Student E: ”Yeah, it’s not keeping on one colour, it’s just..”
Student E: “So you see, it changes colors but very rapidly, and for some reason it just stops on one color.”
Researcher: “Yes, yeah exactly. Because you’re sending it all of these colors.”
Student E: “Don’t we need it to play?”
Researcher: “SO I think we need a hold”
Student E: “So what do I do with this?”
Researcher: “So, let’s think about it… so what you want is..”
Student E: “So it stays on one color, rather than rapidly going through all of them..”
Student E: “Could you have one SAM that you put in the middle, and then connect that to them and then it stays?”
Researcher: “Yeah, maybe, cause basically, you want all the different colors, and when you press the buttons it goes to a random one first…”
Student E: “Is everything connected to this?”
Researcher: “Because that’s still just 3 colors”
Student E: “No, but if you put that there, could it pause and put three colors.. It just does it randomly and it just adds three colors into it”
Researcher: “No, that’s not how that works. RGB is literally just 3 colors. It won’t just pick up any color. It will always be just Red, Green and Blue, what it stands for”
Student E: “So I need to use these”
Researcher: “OK, yeah, see, it does this weird thing. Student A was trying to do it last week. It does this weird thing where once you press it, it’s acutally a SAM bug, the brightness goes all the way down. So if you press it, now the brightness is high, and then you press it, and the brightness goes all the way down. And I think it’s the hold that does that. Instead of holding it, it turns the brightness down.”
Student E: “So, it won’t work then?”
Researcher: “So, I don’t know. Maybe there’s another way we can do it…The hold has this bug but..”
Student E: “We can delay it instead.”
Researcher: “The thing is what the delay does, it doesn’t turn it on.. “
Student E: “Oh it doesn’t hold it does it?”
Researcher: “No it just delays when it goes off. Try it, try it, see what it does”
Researcher: “So you probably don’t need these… you’re already connecting it this way, you don’t need these direct ones”
Student E: “So maybe it will work with the delay..”
Researcher: “How long do you want the delay for?”
Student E: “2 seconds”
Researcher: “Yeah, so… you can either have 6 lights, or can you have a number? So that depending on what number you send, it will turn on a different light.”
Student E :”But then we’d have to randomise the number you send.”
Researcher: “Well, yeah, that’s what I was thinking, but.. The problem is, you can’t send a number to a color.“
Student E: “No, but if you put.. It’s sort of like Scratch. If you put a variable with a number..”
Researcher: “Sorry, how?”

Student E: “Well, I don’t know how it would work, but I’m just using Scratch as a .. so if you, say if you have a block, and you have something broadcasting it. And the color receives a certain number… it hits that”
Researcher: “So you’d have one color?”
Student E: “No, I don’t know, you’d have one number randomiser, and one broadcaster, and if it received it, it lights that color. I don’t know.. How you’d do that”
<worked out the goal but not willing to put in the experimentation to actually do it>
Researcher: “You’re basically doing something like that <pointing to Student A>”
Student E: “Yeah, but with colors rather than voice”
Researcher: “Get the simple code from him. It’s very simple. What’s in here has already a bit of code it in, so you only need one line.”
Student E: “I got him to send it over. So I’ll copy and past it. Which blocks are the numbers?”
Researcher: “Yes. Then you compare.”
Student E: “urgggghh” <as I walk away. He is clearly frustrated with the kind of support I give him. I don’t just give him the answers, I don’t just get it done for him. This is frustrating to him.>

Student E: “I’ve typed it in now, now what do I do?”
Teacher K: “OK.. so just press OK and test it”
Student E: “Wait, I need to get rid of that.. I’m going to restart this..”
<he keeps looking back to copy Student A’s SAM code>
Student E: “What are you doing? I need 6.”
Student A: “I know. But it doesn’t work. I’ve tried it.” <keeps doing the graph for Student E>
Student E: “Why is it so messy now? Man, calm down.”
Student A: “I’m just doing your board game now.”
Student E: “Thank you Student A.”
Student E: “Wait wait, do I just drag it from Javascript now?”
Student A: “Yeah”
Student E: “Where’s my light gone? Did you steal my light?”
Student A: “I didn’t steal it, it was on the floor.”
Student E: “Hey, hey, look, wait, watch. I’m going to press this, and sometimes it flashes.”
<they walk back to Student A’s desk>
Student E: “Student R, random colors. Student R, look”
Student R: “Yeeeeey. Yes, I’m happy.”
Student R: “Student E, Student E look.” <Student E doesn’t look>

Student E: “So, it works, but there’s one problem that I’m seeing. Just watch the light, sometimes it goes two colors rather than one. When I press quickly, it shows one color and then it changes.”
Teacher K: “OK, so maybe that’s something to do with the code… so that’s what you’ve got to play with now. Take one as an example, and just put a Hold, it’s just something that… where would the hold be.. So the message is coming through here, it decides which one its’ going to do, but then it flips over there too soon. And what happens when you press it?”
Student E: “No, sometimes when you press it, it goes from one color to another quickly. Like that. And sometimes it doesn’t.”
James: “That could be, that could be a bug. You can just press it, and release without holding it too much. If you hold it down for too long it does that. It’s like 2 holds.”
Student E: “Oh, is that why it does it?”

<Teacher K had to work it out for him>
Student E: “Yeah. So if you just hold it like that, you can just put that in your instructions. Because if you keep it down, it sees it as two presses.”

Researcher: “Yeah, but I don’t think it’s a big problem. Because it still settles on one light.”
Student E: “But Student A said there might be a problem, because these two colors are two similar.”
Researcher: “I wonder if it switches from one color to another briefly, and it mixes them for that split second”
Student E: “So should I try to make this a different color?
Researcher: “Oh, I definitely would definitely make them as different to each other as possible.”
Student E: “But I don’t think I can. I can’t just set that to..white”
Student E: “Now it’s doing it all the time. It’s doing it all the time. It just did it a second ago. “

Researcher: “Oh look keep it pressed, it’s one color, and then you release it it’s another.”
Student E: “That’s what Mrs K said.”
Researcher: “Well that’s what it is, look. If it’s pressed, it’s one color. When you take it off, it’s another. “
Student E: “So can I have a timer? Maybe a Hold. So will a hold work?”
Researcher: ”Yeah maybe.. It might hold the instruction.”
Student E: “And how long do you want it for?”

Student E: ”That doesn’t work”
Researcher: ”Ohhh it’s because it’s because… you’re holidng, and hten setting a random thing.. Try putting it here.. On no the randomiser, try putting it here. “
Student E: “Now it’s not working it at all. Oh wait I might have to deploy it again. I don’t get it.”
Researcher: “It’s doing it?”
Student E: “Yeah, it does.”
Researcher: ”Oh, that’s looking better, it’s it? Holding for let’s say… let’s hold longer… let’s do.. 2 seconds.”
Student E: “Yeah, it needs to be smaller. I think I need to sort out the delay. If I put this down to…”
Oh look, if I take it down to under 1 second, I didn’t even press it and it changes colours. Now it’s changed colours. Now it’s changed colours. Because of the delay.”
Researcher: “You know why? You know why?”
Student E :”When I did it to 70…”
Researcher: “So without the Hold, what you’re doing without the Hold..”
Student E: “No it’s still, it still works.. Oh, is it called Hold?”
Student E :”No, not even… it was working a second ago.”
Researcher: “Yeah..”
Researcher: “Do you understand why it does that? Let’s say without the hold, do you understand why it switches colors?”
Student E :”No.”
Researcher: “Because, le’s take the hold off again, now press it. Keep it pressed. Now that’s one color. Now release. Now another colors. It’s basically sending 2 instructions. One instruction when you press. One instruction when you let it go.”

Student E: “So, how do I fix that?”
Researcher: “I wonder … let’s try a toggle. “
Student E: “What’s a toggle? “
Researcher: ”It’s an on/off. It turns it on, or it turns it off.”
Researcher: “So in this case, you’ll have to press it twice. Because one will turn it on. And the second time it will turn it off. So the first time you have a color, the second you kind of reset it.”
Researcher: “You’ve done it. It actually works.”
Student E: “But sometimes it doesn’t work. Sometimes it does it once, sometimes twice.”
Researcher: “No, no it doesn’t. It doesn’t actually achieve what I wanted, but it achieved what you wanted. So I’m not sure why, but it’s actually always sending an instruction, even if it shouldn’t. You did it.”
Student E: “OHHHHH”
Researcher: “You’ve done it.”
Student E: “In my instructions, do I have to write that…”
Researcher: “No, it’s random. So you could get the same color twice. It’s random.”
Student E: “I just have to press it 4 times.”
Researcher: “It’s random though right. Thing is, it’s different players. So one player will get one color, and the other will I get maybe the same color. But that’s OK. It’s random. With a normal dice, you could end up with number 3 four times in a row.”
Student E: “Oh yeah.”

Teacher K: “You’ve fixed it?”
Student E: “Yeah”
Teacher K: “So what does the toggle do?”
Student E: “So it acts like an on/off switch. But it should work so you have to press it twice, but it actually doesn’t. So you just press it once. But sometimes you have to press it multiple times, because the randomiser lands on the same color. So if I just go press… “
Teacher K: “So you just have to put that in your instructions.”
Teacher K: ““If you get the same color as the person before you, press twice.”
Student E: “Yeah”

Student J: “I made a spinner!”

Researcher: “Do you think this will work like this?”
Student J: “Yeah. I’ve tested it. This is an old.. And it spins on a random number. Well it’s not random but it’s got a different timing to it.”
Researcher: “Nice. And are you going to do anything else in SAM?”
Student J: “I’m not sure what else I could do..”
Researcher: “I don’t know if you remember, but at the beginning Teacher K put up some options of what you might be able to do, as well as a spinner, hat might happen when you land on certain squares, lights and noises..”
Student J: “I was going to do this thing, with light sensors. But because of the board, I’m not sure I’m going to be able to push those lights sensors ..”
Researcher: “Hm.. yeah.. Not sure. What are the characteristics of your game?”
Student J <explains the game>

Researcher: “OK, so maybe you can do the count of the points automatically. So what does your game do? You add up points, you move on the board, you’ve already got that done, it counts out the points.. Maybe you could do that.. Then what else do your players do? Or maybe you can introduce some randomness to the game, not just light sensors, but pressure, proximity… maybe you can have a random point at which you can have a bonus question..”
Student J: “Maybe I could use the proximity sensor..”

Student J: “I don’t know what to do…” <to himself>

Researcher: “How did it go today Student J?”
Student J: “Ahm, I think it went well cause I decided to do a bit more design. For each wife I’m going to have a voting of different color. It should be color coordinated based on what color dress she usually wore.” <he means the colors on the board.. This is not related to SAM. He moved away form SAM when he couldn’t find ideas to something else>
<Student J worked on a spare desk next to his desk… I wonder if he avoided the recording. He also recorded little in SeeSaw.. I think he’s feeling the pressure of not having enough SAM elements and avoiding scrutiny / observation / discussion /confruntation / documentation of it>

Student K: “is this even working..?” <as he’s working with SAMs>
Student K: “OMG I don’t even know what to doo….”
<the student did struggle with coming up with ideas of what to do.. What’s feasible, what should work for the game… like Student K, Student J, even Student N. They have ideas.. From Teacher K, from the SAM inspiration videos, I tried to provide them with ideas, from their peers, they could reach out and ask… but for a while, they just get on with other things>

Student K: “I don’t understand, I don’t understand, I don’t understand…”

Student K: “Student L, Student L, if this lights up green.. there’s green blue and red.”
Student L: “Why do you have 4?”
Student K: “Because there’s going to be 4 places.. 4 pressure sensors. These 4 are special places. So it’s gonna light up.”
Researcher: “What are you doing with SAM?”
Student L: “I’m doing the <unaudible>. And Student K is also doing the light sensor that we started last week, but he didn’t finish, so he’s just trying to work it out.”
Researcher: “So how is it going to work?”
Student L: “When you move your character and it will land on a space, it will land like this, and depending on what color goes off, you can move forward or backwards.”
Researcher: “OK, nice. And did you get it to work last time? Is it working?”
Student K: “I got it to work last time, but now the light sensor doesn’t work…”
Researcher: “Do you remember what you need between two blocks to manage the level of light?”
Student K: “Ahhmmm…”
Researcher: “It’s actually a filter.”
Student K: “Oh yeah yeah yeah”
Researcher: “You’re almost there, you’re getting there, you’re getting there”
Student K: “Oh, it works, it works!!! Student L it works!!!” <can’t believe it himself>

Researcher: “How’s your sensor, how’s your sensor?”
Student K: “It’s not working.”
Researcher: “No?”
Student K: “Well, it kind of is but…”
Researcher: “Oh, it dims the brightness… yeah, we saw this with Student E as well. It’s really annoying. Did you have this problem last time?”
Student K: “Ahhhmmmm..”
Researcher: “Hm, I wonder if you introduce a Toggle… no no, you still need the filter, don’t remove it, you still need to measure the amount of light coming in. But the toggle acts as an on/off, I wonder if you use that it will keep the brightness.”
Researcher: “But because now it’s off… does it work?”
Student K: “Yeah”
Researcher: “Can you see what happens? As long as the light is within this value, it will keep flicking between on and off.”
Student K: “Yeah”
Researcher: “But it’s not really what you want. But it’s a workaround because at least the Toggle doesn’t turn the brightness down”
Researcher: “I wonder if you can use a different block instead… Now if the light is on, it will flicker. It’s a workaround, a compromise. Do you think it works?”
Student K: “Yeah”

Teacher K: “What have you been making today?”
Student K: “We’ve done a light sensor..”
Teacher K: “So what does it mean for your game, when the light goes off?”
Student L: “If it goes green, you spin the spinner and that’s how many places you move forward. If it goes red, you spin the spinner and that’s how many spaces you go backwards.”
Teacher K: “Ohh. And what’s the blue? Stay put?”
Student L: “Ahhm… yeah, stay put. Not sure.”
Teacher K: “Yeah, stay put, that’s good”

Student A: “So if you land on a square…”
Student N: “You know you can use the RGB…”
Student A: “That’s just a cycle..”
Student A: “I’ve got the random generator working with lights..!!”
Student A: “I made a random color generator”
Student N: “But you don’t need those, you don’t need the numbers, you can go straight to the colors”
Student A: “Yeah I know I just didn’t take them out… I’m lazy..”
Student N: “Go on, take them out, I want to see this.”
Student A: “Ohh”
Student N: “Ohh, ohhhh… oh my goodness… Oh, it only worked once :(“

Teacher K: “We’ll ask Researcher as she might know it better but.. Have you tried though Holding it, using the Hold?”
Student A: “I tried it last week. But it didn’t work…”
Teacher K: “If you hold that button too long it’s taking two presses?”

Teacher K: “It’s a firm click. It can output the same color twice, but that’s just random.. I just wonder if you press it and you have a Hold. You don’t even need a long hold, just enough to…”
Student A: “Just 0.5 seconds”
Teacher K: “Like you, I’m just guessing here..”
Teacher K: “You need to test it live, get the button, and get somebody else to actually press the button.”
Student A: “Sometimes when I press it it goes, it goes to one color and goes back…”
Teacher K: “So is it better to take the hold out? And test it again?”
Student A: “I think I’ve got it. Mrs K, I think I’ve got it. I was trying it for a while, and every time, when I pressed it, it would switch to one color, and then change, and it would go back again. So if I did it again, it would be a different color, and if it’s the same color again…”
Teacher K: “So what are you going to do?”
<Teacher K has a very different attitude with Student A, who she knows will test an work it out himself. Rather than taking over his computer, like she did with Student K numerous times, she is very hands-off, doesn’t offer much as suggestion, and walks off with the question of .. what are ***you*** going to do? Saying that, a bit earlier she did sit down at Student A’s computer to test the randomiser with him, and offered one suggestion. But still, she was comfortable to mostly encourage him to test some more. She is also out of ideas - she doesn’t actually know how to fix the problem, so she’s more reluctant to ‘help’ in a more traditional sense>
Student A: “Well, I don’t know. Because after I clicked it, the second time it would change and go back to another so…”
Teacher K: “Right, so let me test it. So I’m playing your game, and I do this..”
Teacher K: “You just have to say… slight problem with the game, if it doesn’t change, you have to press it twice until it does”
<Student A is unhappy with that suggestion>
Teacher K: “So if that happened to me like that, I’d have to press it again.”

Researcher: “See, that works with the toggle now doesn’t it?”
Student A: “Yeah.. but why does it work?”
Researcher: “I don’t know.. I think it’s because it’s actually 2 instructions. With the press and the release it’s just one instruction to the toggle, and it sends just one instruction further on”
Student A: “yeah..:) “
Researcher: “I tried it by chance, randomly, and it happened to work”

<there is often a mixed aim with the documentation: on one hand, it’s about actually finding out what the students are actually working on, what their goals are, what they are trying to achieve. Why did they build that with SAM? Is it complete? Does it work as expected? Do they want to change it at all? What exactly have they done and why? Just to know exactly where they are at, so that they can be helped.
On the other hand, it’s about the evaluation - how much effort did they put in, how much did they test, change, adapt, learn? How well justified are their actions?>

Student N: “Mrs K, would this work?”
Student N: “It’s a random noise for now, but maybe a trumpet noise when you open the box..”

Teacher K: “Yeah, that would work nicely. Haha. Go and look for sound effects on google and find the right one, and it can be great when you start the game”

Lesson 12 - 27th November

At the beginning of the lesson, Teacher K tells them they only have 3 lessons left, but realistically only 2 since there will be carol practice. So ‘stop wasting time coloring in, or 3D printing, and focus on the ‘main crux of the game’, which is are the game elements themselves using SAM. She encourages students to plan their boards in detail on an A3 piece of paper to plot out what they have already, and what they will add. She focuses the lesson on SAM.
She is worried there is not enough technology in the game, and that students haven’t added enough elements. She is also worried they spent too long on other elements - 3D printing, design, etc. She is trying to focus them on what she thinks is missing most which are the SAM elements. She is panicking slightly herself with the lack of time to produce something interesting with SAM. Is she devaluing / underestimating the solutions the students HAVE found so far, and has the impression that they’ve done very little? Because of the little visibility she has over how much the students HAVE experimented with SAM?
But at this point, her focus is also almost entirely shifted to the final result.
She directs them to build a trap door, and she built it herself as an example with a 3D printed axe. She shows it to the students and directly encourages them to build it, as a fun element, with an axe, a noise saying ‘you’re out’, etc. She goes round and shows all the students her prototype.

Student F: “Can I do SAMs?”
Student F: “Can we go on SAMs?” <logs in>

Student Ad: “Today I’ve discovered about servo, which is like a, so when you, on the board game, I’ve got a jail. So this is basically like a jail, and this is a door. So when I put a door on, imagine that it opens, and I can put an actual cage with 3D printing. On the board game, Ialso have the code, that, how you have to collect the through the board to get to the gate here. The gate will also be controlled by a servo, which will open the gate. I’ve also had this other idea inspired by Mrs K, which is about a ‘off with his head’. So basically if you’re on any of these spots, this controller with an axe will go down and you’re basically out of the game.I will have more than one servo-motor. I also have our board design now, it’s all designed out with its special places. I’ve had this great idea about Henry’s new wife. So basically, it will play music and do the lights I’ve just show, and it will make it so that instead of, let’s say you get 3 on the spinner, you get to move four spaces. Yeah, I think that’s it. I’ve designed it out, put all our special places, and that’s it. Oh, Student F had this nice idea where we have a Tudor background.

Student R worked a bit with SAM, but not much documented in video - they mostly fought over Student R ‘not doing anything all lesson’. But Student R did little bits, mostly fighting Student E off and his accusations and threats of ‘not doing anything’, and Student E didn’t do a lot either - he mostly copying the same random light color randomiser (no additional

SAM testing), and spent time accusing Student R of not doing anything. Student R tried to engage Student E, but Student E was just agressive and stand-offish. :(

Student E (presenting to visiting student - SeeSaw video): “This is a randomiser for the dice. Instead of having a dice, you have a color. You can have color, so blue = 1, red = 2, etc. So you press a number, and if it’s one of these numbers, it will go into a color and light up.”
Student R (presenting to visiting student - SeeSaw video): “This lesson I figured out that this light fits in here in the castle…Then I spoke to Mrs K about it… Then doing this with the RGB… Then trying to figure out when our characters land here, it will work with the pressure pads.”
<Student E keeps interrupting at every sentence telling him either that it’s basically nothing, that he’s wrong and the idea will not work, that it was him that actually did that..>

Student Ed: “I have a pressure sensor here…”
Student N: “Pressure sensor..? The proximity sensor works with the servo motor. What do you expect to happen exactly?”
Student Ed: “It will say ‘you are dead!’”
Student N: “I can have a scream!”
Student Ed: “Yeah”
<Teacher K comes over and shows them a servo-motor with a 3D printed axe on it>
Teacher K: “And you can have a scream with it”
Student N: “I need a proximity sensor for that”
Student A: “I have figured it out! I have figured it OUT”
<both Student A and Student N are working in SAM>

Student A: “I have a question…”
Student A: “I need help with something. From the thing about the toggle before, I’ve put this after the color, so if I try this, wait, it doesn’t work, even if the pressure is full…”
<examples of discussions around how specific blocks work and how they can serve the students’ purpose>
Researcher: “And now it works well”
Researcher: “Yeah, cause before you had the toggle… “
Student A: “This was the testing bit”
<again, proof of separating between final artefact and test>
Researcher: “Yeah.. it’s because, when you take the toggle here, when you press the button it gives the instructions and the toggle is a bit confused. Because after the button, the toggle knows what to do. If the button is on, it turns on, if the button is off, it turns off. But after the color it gets confused, it doesn’t know what to do with the color instruction going into it… i think. Not sure. But that works really well now doesn’t it, and it doesn’t flicker between colors”

Researcher: “What are you thinking of doing?”
Student Ed: “Maybe when you get to the end, press this button and it flashes a light… actually make it multi-colored”
Researcher: “So what does the RGB do?”
Student Ed: “It could be this one, or… where is the motion sensor?”
Student N: “I don’t know”
Student Ed: “OK, go to SAMs”

Student N: “OMG, auto-cycle! Yes, this is it!”
Student N: “Oversensitive”
Student J: “What is that block there N?”
Student N: “Which block?”
Student J: Oh is it custom code? Did you write it yourself?”
Student N: ”No”
Student J: “Did you find it on the Internet?”
Student N: “Yeah, Researcher helped”
Student J: “Look I’ve got my servo-motor. Nick, look at this. This is my servo-motor, look what it can do. I made it so I can push it back with one button”
Student N: “Is that a 90 degree circle”
Student J: “It’s 120. I actually didn’t <inaudible>”

Student N: “Is there a way to duplicate a SAM block?”
Student N: “I want to get this into the one here”
Researcher: “Yeah you can copy that code..”
Student N: “And I just paste it in a new one”
Researcher: “Yeah”
Researcher: “You might not be able to… Paste it there instead. And remove the duplicate bit at the top.”
Student N: “Is that it?”
Researcher: “No, it’s all these 3 lines. Cause they are duplicate aren’t they?”
Student N: “Oh yeah. I remove all this then?”
Researcher: “Not quite, you keep the curly bracket as it’s the end of the function. That’s it.”
Student A: “Oh, are you doing a random color generators?”
Student A: “You’ll need a toggle here. Because it flickers between colors”
Student N: “What do you mean it flickers..?”
Student A: “You need a toggle here, without it it will flicker between colors”

Teacher K: “OK, so what are you doing?”
Student N: “I’m doing a random color generators. If you land on a block…”
Teacher K: “It randomly chops his head off”
Student N: “Yeah but the idea is…”
Teacher K <doesn’t let him finish>: “And what are your..”
Student Ed: “I’m testing this”
Teacher K: “Are you understanding it?”
Student Ed: “Yeah”
Teacher K: “You also need to tell me what that does at the end”
Student N: “Wait, can we have a random …”
Student A: “Pressure pressure pressure”
Student A: “Wow wow, Student Ed, Edie, look” <servo-motor spinning??>
Student N: “I’m super confused…What are you trying to do though? Do you want the servo to be random or an axe?”
Student N: “Student Ed, I’m about to get rid of that yeah?”

Student Ew: “How come Student Ed gets the good one?”
Researcher: “I’m sure Teacher K will 3D print another one of you want”

Student N: “Student A, where did you get scissors? Hey Student Ew, can you give me the scissors?”
Student N: “The filter is too hard. Wait”
Researcher: “Is it working?”
Student N: “Yeah, I’m going to try and fix it so that… I’m going to add an axe to the end of it now. But I haven’t really yet.”
Researcher: “Nice. And what’s it going to be triggered by?”
Student N: “The button. It’s going to be at the edge of the board so that it has space”
Researcher: “Yeah, and you need to play around with the filter for it not to go off when you don’t want it to”

Student N: “What’s happening?”
Student A: “I connected my house to his computer and I tried to take the servo back from Student Ew… bad boy”
Student N: “No way :)”
Student A: “Student Ew, stop messing around!”

Student N: “Student Ed, can you stop with the motion for a second? Please! I’m going to try and take it out of range”

Researcher: “Is it working?”
Student A: “No.. cause I was planning to make it random, so that you don’t get knocked down necessarily.. It’s a chance, so it will say ‘You get to live, well done’. So I’m just testing it out..”
Researcher: “So what does this output?”
Student A: “It’s a random number generator”
Researcher: “From what to what?”
Student A: “From… what do you mean?”
Researcher: “Between what numbers does it randomise, what’s the range?”
Student A: “0 to 7”
Researcher: “Hm… does it work if you just connect directly?”
Student A: “Yeah”
Researcher: “Cause you see, if you press the button, it does actually turn on the screen”
Researcher: “Cause you’ve got the toggle as well, so that will turn it on and off..”
Researcher: “How about changing that to go just to 2 rather than 7… so it can be either 0,1 or 2”
Student A: “So if we put it between 0 and 1.. Doesn’t work :(“
Student A: “So what if we do..”
Researcher: “Hm.. yeah, no, I don’t think that will work..”
Student A: “No..”
Researcher: “So what do you really want? You want to go, so either.. I think there’s a different way of doing it. Because you don’t really need the custom code here, you only really need 2 options you don’t have 6 like for the dice. So I feel like you can do the 2 different options in a different way.”
Student A: “Use 2 sound players, and if it says ‘off with his head’, there’s just another button and you press it for the axe to come down separately, and the servo goes..”
Researcher: “SO what have 2 buttons?”
Student A: “Yeah”

Researcher: “Yeah.. you could do that. Although this was cooler, because then you could have it random, so when you press they button you don’t know what you’ll get, which makes it more fun. Hm…”
Researcher: “Yeah, so this should.. I don’t know why this doesn’t work. Let’s try something else”
Researcher: “Now… let’s try that. So the randomness now definitely works.. Now let’s try that”
Student A: “Yes”
Student A: “No because this is up to 3”
Researcher: “Yeah, but I think, if you try again with the player I think, now, the randomness works between the two paths”
Student A: “But you see, it does that…”
Researcher: “Yeah, I have a feeling it’s there, let’s try that”
Researcher: “I don’t … hmmm”
Researcher: “Cause sometimes it’s just the player, sometimes it’s just the servo, and sometimes both. With the 2 players, it works as it should.”
<he is fine with saying it’s not working atm… and separating it as a test to get it to work>

Student A (presenting to his visiting student, SeeSaw video): “This is a random color generator.
The LED will go through these colors. This is the random script. And this goes through here and whichever number it is, green, blue or red. The same thing but with a button with SAMs, so you press a button and it tells you how many spaces to move. And this is the testing, still work-in-progress, we’re trying trying to make the servo move and the sound to go with it.”
<Student A super comfortable with the unknown if the trap door will actually materialise into something that is random or not… still work in progress, still testing, still unknown… but trying things and building on the information gained from each test>

Student Ew (presenting to his visiting student, SeeSaw video): “Yes, this is my board. I’m just adding SAMs. I’ve actually not done this on the actual board yet. These boxes will be 4.5 cm big, here is going to be a beheading centre. And this I made a box, and this will fit exactly in the box, and it will fit exactly in the beheading centre, which will be … And it’s going to be questions, if you get it wrong, the axe will go off, but I still need to print the axe.”

Student N: “Student Ed..., wait wait wait, I want to add something to it.”
Student Ed: “It’s the paper one you just made”
<Another display of clear understanding for tests versus final result - the paper axe>
Student N: “I’ve got something really good here, hang on. It’s going to go through the Delay, then it goes through the SAM player, then it goes”

Student N: “Hey Student A, for a randomised thing here, would it work if I have a yes or no?”
Student A: “Do you have a picture for the custom code? Can you show me the custom code we have for the randomiser?”
Student N: “Here”
Student N: “Student A, would it work on two things?”
Student N: “Perfecting the kill…”
Student Ed: “DIE”
Student N: “Done? Space space..”

Student A: “Yeah”
Student N: “Wait, let me see if it works”
Student Ed: “How do I log into SAM? N, can you… How do I do this?”

Student N (talking to his visiting student): “It’s a servo… OK let me explain. I’ve got mine working with a motion sensor. It’s a motion sensor with a filter. So if it’s 60 to 100 it will go off and it will turn 180 degrees and it will also, you can head this through the headphones.”

Student N (presenting to his visiting student, SeeSaw video): “This is a proximity sensor, and it’s from 60-100 and it will trigger the servo and the scream, and the servo will spin like this. That’ the one they gave me, it’s the same, it just has a 3D printed axe on it, and it goes when you press the button.”

Visiting student: “So is this your board? How does it work?”
Student Ed: “So basically, you have piece and you move among like that. You have to get to the finish and whoever gets there first wins. It’s like Snakes & Ladders”
Student N <handing over the SAMs to Student Ed>: “You can mess around as much as you like”
Teacher K: “Right, boys, so what are your SAMs? So you have the light sensor..”
Student N: “Yeah, when you open it, the axe will be somewhere on the side..”
Teacher K: “Right, so you have to draw that..”
Student N: “yeah”
<Teacher K walks away and shows them a board design on a big piece of paper>
Teacher K: “Look look, look, like they’ve done, they’ve planned their board in detail, and it shows exactly where everything is going to do… I want a plan, in detail, of everything you’ve got so far, where your SAMs are going to do, all your technology mapped out, like this, with everything written down”
Teacher K <coming over and tidying their desk, putting a blank piece of paper in front of them>: “Right, nice and neat, write it all down so that I can, in one glance, know all the SAMs you’ve got. This group have got it nice and tidy.”
<Student N seems flustered. He didn’t realise there was something he was supposed to be doing that he hadn’t already. He thought he was supposed to work on SAM… Also, they’ve got it already half on the inside of their pizza box. Nevertheless, he gets to work. Again, the conflict between the recording for the students’ sake, an the recoding so that the teacher knows exactly where the student is, what they have done up to that point.. Which of course only has the stuff they’ve decided to keep.. The finished product. At this point, the more they’ll have, the better… which is not necessarily success criteria.>

Student L: “If they take more than 10 seconds then..”
Student K: “Off with your head..!!”
Student L: “If it goes more than 30 seconds.. That’s plenty of time, off with your head. That’s a fancy way of doing it”
Student L: “Lights color, green go forward, we could do a random color, do it a random color, green, orange..”
Student K: “How do you do a random color? I don’t know how to do a random color?“
Student L: “I don’t know, you’re the SAM dude!”
Student K: “I’m not the SAM dude..ohhh my head hurts”
Student A: “What do you want help with?”

Student K: “So when the pressure pad is pressed, it goes either green, red or yellow.”
Student A: “Fine. You could just use green..”
Student L: “I want to do it random”
<Student A does it for them>
<Student K doesn’t accept that he can test the SAM stuff on this occasion, he is more final-product oriented for the random color generator.>

Student L: “To move forward you have to answer the question, and if you get it right you spin the dice…”
Student K: “Yeah”
Student A: “Are you using a pressure pad?”
Student K: “Yeah”
Student A: “How did you get it to work?”
Student K: “I just turn it off and on again”

Researcher: “Wow, you’ve got a lot of stuff on there, that looks good”
Student K: “Yeah but I can’t get it to work..”
Researcher: “What have you got there? What are you trying to do? Does it work?”
Student K: “Ah yes.”
Researcher: “And what does the color mean?”
Student L: “If it’s green you get to move forward, and it’s red you go backwards, and if it’s yellow you have to answer another question”

Student L: “Student K I’ve got a great idea. We can have a shortcut, and we can have questions to go in that shortcut, if you want. And if you don’t, then you have to go back 3 spaces.”
Student K: “Ahm, yes, yes”
Student L: “Isn’t it an amazing idea?!”
Student K: “Yes”
Student K: “This is annoying… somebody help me!!”

Student K (presenting to visiting student, SeeSaw video): “So it’s a pressure pad, so that when a player lands on a space, it turns into lights. And for each color, there’s a different instructions for the players.”
Student L (presenting to visiting student, SeeSaw video): “I’m working on the board. So we have pressure pad, when you land on these spaces it goes a different color. You can answer questions, you can do that…”

Teacher K: “So how are you players going round the board? Is it just by answering questions? Are you stretching yourself with what you could be doing? Are you putting effort in or are you just cruising..? Is it because you don’t have any ideas of what to do, or is it because you don’t know how to do them..? That is the million dollar question isn’t it..?!”
Student K: “I need something extra.. To make the players move around.”
Student L: “Here is the servo-motor, here to serve and protect :) Wait, does that go up and down? Yeah it does. But how do I put it on the board, like physically?”

Student J: “yeeey!!” <got his trapdoor working>
Student J: “Oh, you could make robots, you could have robot legs!”

Student J: “How did you attach the 3D printed axe?”
Teacher K: “The axe? I just glued it on, you can do it with superglue or sellotape”
Teacher K: “You can use a paper one as a test, cut one up and glue it to the servo as a test”

Student K: “Are you going to screw that into the side of the board?
Student J: “No, I'm going to build a tower, so that the axe comes sideways and puff! Yeah, it's the aspect of fun!”

Teacher K: “How is it going Student J?”
Student J: “I've been working on the trapdoor. I think it works. But my servo keeps dying.”
<Teacher K moves him out of his seat for her to take control of his computer… ARGHHHH!!! Totally >
Teacher K: “Is the servo charged? Let's take off for a second any additional blocks..”
Student J: “I had two blocks, to go both ways”
Teacher K: “Yeah, so it does work, you just need it charged. Does it have to go both ways, don't you just knock them out?”
Student J: “Well I'm trying to built a trap-door to take the characters out. And then …”
Teacher K: “OK, so try putting this back then… which one is it, switch direction?”
Student J: “Switch direction yeah”
Teacher K: “Cause I've got a feeling… test which way it's going. Right, so that's going …”
Student J: “That way, and then that way”
Teacher K: “Is it working then?”
Teacher K: “Right. Is there a way to make it speedier? Is there a way to make it faster? Is it is one of those that is the way it is?”
Teacher K: “It definitely reverses does it? That reverse block is definitely an issue… I wonder if switch direction would be better. Cause remember before we couldn't get it to…”
Teacher K: “Ask Researcher as well, she might know.”

Researcher: “Oh, it doesn't work at all does it? But I wonder if it's just because it's charging. Yeah, cause look, it's even off. It wasn't even on. It had the charging light on, not the block. It might of turned off since it had no battery.”
Teacher K: “Yeah, cause I wondered if it had issues because of the switch direction block…”
Researcher: “Yeah, no, I think it just needs a good charge. I think it does work once it gets charged properly.”
Student J: “but it's on… but now it does work”
Student J: “I think it's the power”
Researcher: “Yeah, I think so. Cause it's too random otherwise, as soon as you plug in it works, when it's not unplugged it doesn't… Leave it to charge properly and it will work”

Student J (presenting to visitor student, SeeSaw video): “So the top thing is a spinner, it's sort of random, random between the different selection numbers and times, and then I have a piece of cardboard underneath. And then atm I'm making a servo, with a sort of sword on it for a test. Once I fully charged the servo, I'll make it go back and forth, so that it hits the characters once they finish their go.”
Student Kr (presenting to visitor student, SeeSaw video): “Basically, this is my board and there's 6 players. Each player gets questions, you can use the spinner to move 1, 2 or stay on the same square.”

Student J: “What’s that website where you find 3D printing stuff?”
Student Kr: “Thingyverse. Do you want to find an axe?”
Student J: “No, I don’t want an axe, an axe is too…”

Student J: “I don’t think Student Kr should be doing that. I think I’ve come up with all my SAMs”

Teacher K: “Right, so where all the technology? Where are your SAMs?”
Student J: “I’m not sure what else to do…”
Teacher K: “Where’s the box that knocks out the players..?”
Student J: “In the tower, it will knock the players sideways…”
Teacher K: “OK, but where’s all the technology?! Does it not land on anything?”
<Keeps repeating the same question over and over…>
Student J: “I was thinking… right at the end we could have light sensors..”
Teacher K: “How are the questions answered? Can you not have something on these spaces, something like a trap-door or something?” <keeps banging on about the trap door…. They’ve already go it!!!
Student J: “I could do it so that if you touch it, it opens up and the character falls through it.”
Teacher K: “You just need more technology. “
<THIS IS IT: the goal of the lesson. How much technology do they have already and how can they have more?! Final product focus back again>

Lesson 13 - 4th December

Teacher K re-iterates the plan for today to focus on finalising how mechanics of the game, as well as the learning expectations:

- Do you understand the concept of 3D printing? How does it work? What are the basic functions of 3D printing?
- Can you use a computer program or online system that allows you to design your 3D printing?
- Research solutions of the problem
- Use of prototypes to build electronic systems - inputs, outputs, etc
- Understanding of SAMs and electronics
- Understanding if iterative processes, etc.

I’m not going to go through all of them cause we don’t have time but by the end of this project you will need to be able to tell me about these things.

Student J (speaking to SAM representative): I only introduced the servo into the project last week, so I had to play around with it, try and get it to work.
<comfort with testing and prototypes>
Student J (speaking to SAM representative): “I’ve made a spinner here, by using code, so it’s just random. Then I’m making a servo. We were told that we had to make the game a bit more fun. So I;m building a tower, and when the players go past it will hit them. And then I’m using other servos, with a cardboard stuck to them, that I’m going to put under the board, so

every so often they will fall down. We have 2 buttons. This one goes this way, and the other one goes the other way."
SAM representative: "How did you come up with the idea for what to build for the game?"
Student J: "I was really stuck for ideas, so I was just thinking of ideas, and then I found the board. I was sort of starting to design it a bit like chess, but then I couldn't add much SAM into it, so I decided to add questions."
SAM representative: "When do you use sleeping SAMs?"
Student J: "I just use sleeping SAMs to test stuff. Then I come in here and use the actual blocks. Sometimes it works, and sometimes it doesn't."
SAM representative: "What are you going to do now?"
Student J: "Well, I don't know if it's a button or a servo, so I'm testing it out."
<again comfort with testing, embracing tests as unknown outcomes - it might work, it might not. Using sleeping sams specifically for tests, and testing more blocks>

SAM representative: "So, you're doing this in SAM?"
Student J: "Yeah, but it's not finished, I still have stuff to do."
SAM representative: "So… explain this to me. So this is a button… and another button."
Student J: "This is a spinner I made. It spins and it chooses a random code."
SAM: "So, if I press a button, which one does it choose to go down?"
Student J: "Ahm, I don't know, but I think it chooses randomly, cause sometimes it goes for a long time, and sometimes it goes for a short time, but I don't which one it chooses."
Student J: "So we're building on pizza boxes, so I have these under the pizza box, with cardboard on it, and I'm just testing it with the button. The button doesn't work but then jail works. But I don't know if it's the button because this happened last time as well."
SAM: "Are these paired?"
Student J: "These are paired yeah. It happened last week to me as well. It works with jail.."
SAM representative: "If you take the jail out… it's odd isn't it?"
SAM representative: "So… what are you going to do if it doesn't work that way."
Student J (with a smile on his face): "I don't know really, I usually just, what I think and I just try something else. Cause I was going to have a tower, and some servos in the tower, and have a hold for the button to go into. So maybe use a slider or something."
SAM representative: "So when it doesn't work, you don't get frustrated?"
Student J: "No, cause I don't actually need the button. I can use something else. I can always use a slider, or a sensor, or something else"
<GREAT STUFF :)>
SAM: "So how does this work, talk me through it, so it's a spinner, so if I press a button, you're going on the board, explain to me how it's going to work."
Student J: " I'm going to try and use a hold button or one of these and it will randomly go off every like 10 seconds."
SAM: "Oh so it's a trapdoor."
Student J: "I might be able to put some cardboard down and a light sensor. So when the cardboard goes down then it goes off…"
SAM: "What happens if you fall?"
Student J: "I don't atm, cause we're just trying it out as a basic.."
Student J: "So this is my spinner here"
SAM: "Ah yeah, this works well doesn't it?"
Student J: "I didn't want the game to be fair.. So I have questions on each square, and for each one you answer correctly you get a point. So if you spin 2 you miss a square which

means you miss a question. So then move one square you move from one block to another. And we've got one stay on the same square, like you get another question. I want it to be hard, to get the best out of the players."
SAM: "And are these weighted evenly?"
Student J: "No, this section is slightly smaller on the spinner."
SAM: "OK, so there's nothing inherent in the SAM graph construction to make it less probable to tall onto here. You could make it so that you always start from a specific position, and you calculate the rotations it would take for each option."
Student J: "But then it would make it deterministic"
<conflict with his goal to make the spinner random!!>
SAM: "You don't like that?"
Student J: "No"

Student J: "I was having problems with the servo last week, and I was just testing, and the button doesn't work. When I click it, it doesn't work. So I think the problem might be with the button, not the servo."
Teacher K: "It most definitely is. Have you tested it with a different button?"
Student J: "Yes."
Teacher K: "And no button works?"
Student J: "No. Well last time it was working on and off."
Teacher K: "Intermittently."
Student J: "Well, this is my old project. In my old project I had two buttons. It doesn't even say it moves it down."
Teacher K: "Come out, close it, and go back into it. Cause sometimes it resets it. Because that doesn't make any sense. That should work shouldn't it? "
Student J: "Yeah. I might have to use a slider instead…"
Teacher K: "Student J is having a problem with the button not working. I've told him to come out and come back in again…I'll leave you with Researcher"
Researcher: "How's it going Student J? Is the game coming together do you think?"
Student J: "Yeah <satisfied>"
Researcher: "Is it what you wanted it to be?"
Student J: "Yeah <satisfied>. Hopefully it will work…"
Researcher: "Yeah."
Researcher: "It works."
Researcher: "Do you have anything else to add on the game?"
Student J: "Yeah, at the end we're going to have a tower, get a tower off thingyverse and have a box for the block."
Researcher: "Why do you have two buttons?"
Student J: "One for each direction."
Researcher: "Ah I see. Nice."
Student J: "Cause otherwise it would go back and not return."

SAM representative: Oh wow
Student K: "So when someone lands on a thing, a light goes off, and it tells the player what to do"
SAM: "OK, explain.. Explain the, you've got some custom code there, to do what? Can we have a look?"
SAM: "Oh so you're choosing a random number?"

SAM: “So what does this mean for the game? Oh you’ve got one as well?”
Student K: “I need 5, for 5 places on the board. 5 pressure sensors.”
SAM: “So what’s the board game? How have you planned it out?”
Student L: “So … soo.. It’s like a normal game, so you have to answer questions to go around, and we’ve got a 5 second timer to… do you know the 5 second rule game?”
OK
Student L: “So you’ve got 5 seconds to answer the question, and if you answer correctly, you move forward.”
SAM: “So how do the pressure sensors fit into the game?”
Student L: “So, if a player lands on one, then a light goes off in green, red or yellow, green meaning you get to move forward a certain amount of spaces using the spinner, red you get to move backwards, and yellow you just have to answer a question.”
SAM: “And this is how you decide the color”
SAM: “And you’re randomising a number between 1 and 30?”
SAM: “And you’ve done it as an even weighting? So it’s just as likely to get each option? I wonder would you want to make it so that it’s harder or easier to get one or the other option?”
Student L: “Not really…”
SAM: “Oh, ok… well it’s your game, you should do whatever you want”
SAM: “Pretty good, well I’ll let you carry on.”

SAM: “Can you tell me about what you’re doing?”
Student K: “I’m making a servo, for a trap door. So the players fall through.”

Teacher K: “So the trapdoor, how is the trapdoor going to fit on the box? Where are your things going to fit on your box? Where are they going to be?”
<he doesn’t even have it working, not even as a prototype… and Teacher K bangs on about her main goal: getting students to fit the technology on the board, to get them to as complete state as possible before the SAM reps leave…>
Teacher K <sat in Student K’s seat again… taking control>: “So, if this is your board, your trapdoor is going to sit somewhere here, so you have to think about how the arm is going to go down. Basically, how to attach the servo motor to work here?”
Teacher K: “We can always just do a test. So if we cut out <Teacher K i s cutting out herself>... now really, you should be doing this… This is our practice round, this is your tester, your prototype, because the actual board will be turned around. How is this going to be pulled down? Your test today is how is this going to sit in the board to pull it down? It has to be attached to the piece of card to pull it down? How re you going to achieve that? You can use some sellotape, you’ll glue it eventually, but you can try it in different ways. So you need to experiment. YOu won’t get it right the first time, you need to test, the board will actually be on the other side. So this is your tester.”
<but she hasn’t actually answered Student K’s questions!!!! She stiffles the actual SAM experimentation, the SAM trapdoor behaviour, for her intention that Student K focuses on how the servo works with the board rather than the actual servo SAM behaviour>

Researcher: “How is the game? Is it coming along? Is it turning out how you’d like it to?”
Student K: “No”
Student K: “Well, this isn’t working. I’m trying to put it so that this comes down like that..”
Researcher: “ohhh, is that the trapdoor?”

Student K: “Yeah”

<I walk away as Student K keeps trying. Student K struggles, but he doesn’t ask explicitly for help or doesn’t ask any questions. When someone comes over, he continues to try and avoids detailed explanations of what he’s struggling with. I don’t dig into his struggles, and I leave him to keep struggling… because he’s still trying, and he doesn’t ask any specific questions or for explicit help… so I walk away. Not cool. The temptation is, as log as they are trying stuff, to leave them alone and not to interrupt that trying process, which they are engaged in independently. But.. sometimes they will do things just to appear they are trying stuff, to avoid showing you they don’t know where to go next - check and make sure they know WHAT and WHY they are testing things and have a plan for things working / not working - like Student J with the slider>

Teacher K: “So how is that working?”
Student K: “Well, it’s kind of like this..”
Teacher K: “That’s OK, that’s good. So that would need to be secured, like this. But this will need to be able to be charged, so it needs a box or something to be able to easily take it out. You need your classmate to help you with this. What will trigger the servo? Is it a button? What will trigger it?”
Student K: “I was thinking like, press the button, and then it goes down…”
Teacher K: “You could even have a pressure pad in there. So when it lands on the pressure pad, it opens up.”
Student K: “Can I use a proximity for that…?”
Teacher K: “Yeah, you can have a pressure pad so when the player lands here, it opens up”

Student K: “Let’s get the other thing on. I need a pressure pad, I need a pressure pad, I need a pressure pad. We don’t have a pressure pad, go get it.”
Researcher: “How’s the trap door? How’s the trap door? Does it work?”
Student K: “Yeah!”
<Student A comes over to check it out>
Researcher: “Is it coming together? As you wanted it?”
Student L: “Yeah, mostly”
Researcher: “Nice.”

Student K: “Ah, it doesn’t work. Ah wait, I’ve got it, I’ve got it, I’ve got it.”
Student L: “Wait, you tell me what to do and I’ll do it”
Student K: “Toggle??”
Student K: “Ah, no, no, you don’t need it you don’t need it. Go up, Go up.”
Student K: “Get the button out of the way, get it out of the way.”

Student A: “This? Mrs K told us to invent a way of not using a die for the game, so me & Student N thought of a way to create a random number generator”
SAM: “How did you know what language to use?”
Student A: “Researcher told us ‘why don’t you use Javascript?’, so we found it. So when we press this button, one of those voices with go which is us saying ‘Move 2 spaces / Move 4 spaces’ etc. but it’s random so no one can guess what’s coming next”
SAM: “So have you got any other SAMs?”
Student A: “Ahm, yeah, so this is literally the same as theirs, so when you press the button, it will go through the toggle (because if it’s not there, it flickers), and it gives a color”

SAM: “OK, so you’ve got 3 physical SAMs in total: the two buttons and the light - I see”

Student A: “For the SAMs, where should we put them? So for the dice we’re going to put the button in the middle, but for the random color generator should we put it in the middle or should we change it to when players land on it using pressure pads?”
Researcher: “Ahm, I don’t know, it’s kind of up to you, and what you think will be more fun. Or you could use even a different sensor, like make it when you go near something...”
Student A: “Yeah, but with the proximity, it has to get really close…I don’t know.. yeah, I’m going to try the proximity sensor.”
<again, showing he’s happy to just try it… unknown outcomes.. But he’ll see the evidence>
Researcher: “The button works, but I feel it’s a bit too deterministic”

SAM: “So, what are you doing?”
Student N: “So this is my spinner, and it generates a random number, and I have a recording of my voices.”
<the audio went off as Student N plugged in the headphones, and Student Ed’s monitor was covered for paining… so not much this lesson>

Student N: “Student Ed Student Ed Student Ed, a proximity sensor, as it gets closer, with a 3 second delay..”
<Teacher K takes Student Ed away. I think Student N was explaining his trapdoor>

Student N: “I’ve got a light sensor, and that’s when the box opens. And then I’ve also got a pressure pad, and I’m going to attach the servo motor to it as well.”
Teacher K: “Great, and think about how exactly you’re going to attach it to the board as well!”

Student E: “The thing is, I’m basically done. I don’t have much to do.”
Researcher: “OK, and all the 3D printing is done? Is your board physically drawn on and coloured in and everything?”
Student E: “Yeah, it’s mostly done.. I know what I could do, I can make my thimble character hollow..”
Researcher: “I know what you can do, we can try out the game - from start to finish. Actually play and make sure the rules make sense, etc. etc.”
Researcher: “Yeah but you know the rules don’t you?”
Student E: “But we don’t have the questions”
Researcher: “That’s OK, we can pretend. Yeah we can try it”
Student E: “So I need a pressure pad, I need light randomiser, light sensor.., pressure pad.”
<Student E constantly looks behind his back, making sure I’m sure there to answer any questions / have the backup of the answers in case he has any questions, looks to me for every next step.>
Student E: “And then do I need…”
Researcher: “Filter?”
Student E: “OK, what SAMs… I need to set this to…”
<he constantly speak to his every step to double-check / confirm that it’s right>
Student E: “I like how you can have Sleeping SAMs. It’s about 100 times easier.”
Student E: “OK I need to do one more. A pressure, and a hold.”
Researcher: “No, it’s that..”
Student E: “No, I can’t have it like this see..?”

Researcher: “I think you can, if you position them better you can.”
Student E: ““I just need to sort out these holds. Wait, am I missing…? Now I have to sort this!! This is a pain… Why is that..? This is a nightmare. This has just made my life 200 times harder now.”
Researcher: “Oh you know why, it’s because you’ve mixed your colors when you put them together. So if you separate…”
Student E: “I’m just going to move these out of the way. Why is there 2 connecting… oh no, it’s not. Why is there two...This is really annoying.”<hands over head>
Student E: “OK I need help to sort it out. Wait, let’s just check” *<he reacts independently eventually, I’m still talking to Student R>*

SAM: “Can you tell us about your game?”
Student E: “So this is.. Instead of a dice it’s a randomiser. You have some code here that broadcasts a message with a number between 1 and 6, and then it goes through the number and then it goes on to the LED. And every color light means something, so let’s say green means 6 spaces, etc. “
Student E: “And this is a pressure pad because I’m doing Monopoly and Monopoly has 4 big spaces. This one is for jail, this one is for Go, this one is for when you pass jail, and I need to do another one.. “
Student E: “I’ve made it before physically. But I’m doing this now, cause I needed to move this from a different account.”

Student E: “This will go here. I am going to change the button to.. I think it’s a movement sensor or something...so when you pass it, it will go”

Student Ad: “When you press the button it spins. Ihad the idea that you couldn’t time it to get exactly 4 or 5, so we have a Delay, so it waits two seconds and then…”
“So I’ve had voice recorder, and a code. You need to get the code to get through the final gate. So it’s lots of stuff, all over the place. We kind of invested it as we went along…
SAM: “That’s how it goes.. You adapt it based on what works..”
Student Ad: “Yeah”
SAM: “And have you enjoyed using SAM? Do you find it easier to learn how to code with it?”
Student Ad: “Yeah, it’s got the same concept as Scratch, just a bit more physical.”
Student F: “I just realised, cause there’s too many blocks, so it’s hard sometimes to see what you’re using.”
<It’s a narrative of all the changes Student Ad has made to his game over time…, how he’s compromised and updated his original ideas>

Student Ad: “It’s OK if after this I go over it with a sharpie?”

Appendix H

Teacher Evaluation Interview Script

Semi-structured Teacher Evaluation Interview Script

Teacher Background
1) What is your classroom experience with SAM Labs to date?
2) How do you approach the design of SAM Labs open-ended projects?
2) How do you document and evaluate open-ended SAM projects?
3) What are your main challenges in designing, supporting and evaluating open-ended SAM Labs projects?
3) What is important to you that you see students practice when engaging in open-ended projects?

Ranking Exercise
For 4 students building a trapdoor for their board games, ask teachers to rank the students in order, and ask them to expand on their criteria and reasoning for their ranking:

a) The final SAM Labs design of the trapdoor

b) The 'Distinct Approaches' iterative version of the visualisation corresponding to the four students

c) Did the ranking change? If so, why?

Data Visualisations feedback
1) What can you see in each visualisation?
2) What can you infer about the students' iterative design process if anything?
3) What questions do the visualisations prompt about the students' activity if any?

Potential of using the visualisations in the classroom
1) Do you think the visualisation would add anything to what you normally observe on your students in the classroom?
3) In what ways would you use the data visualisations in your classroom?
4) In what ways would you improve the visualisations you've seen?

Appendix I

Recorded Interviews Teachers Transcript

Teacher A

Session 1

A bit of background: I was a classroom teacher for 14 years, I was a little burnt-out. I was using technology quite a bit in my classroom. It was about the time the iPhone came out and the possibilities of using mobile technologies for documentation was really interesting to me, specifically for digital portfolios and things like that. I had this growing interest of how to use technology specifically in the context of open-ended experiences for children.

Theme: link between documentation using technology and open-ended environments - documentation to empower and support these

As a teacher I work with this idea of democratic education. It's around the idea of teacher and students creating learning experiences together. The start of the year was never 'This is what we're going to do', it was always really 'Let's plan out the curriculum together around big questions and ideas students have and some areas that I'd want to push them into in terms of skills and habits of mind. So coming from that place in my thinking, when coming into this job, I'm the Technology Education Coordinator at this school here in Portland. It's an independent school, essentially a private school for pre-school to high school.
Part of my job and my interests was to develop opportunities for students to have more coding and programming skills as well as opportunities to do really hands-on, physical projects.
So I had years before I started at the non-profit camp called Tinker Camp. It was really a space to, and based on my experience as a teacher too, to get students to use lots of different materials and tools to answer questions and think about the world. So having lots of hands-on, building, making, tinkering experiences was always a passion of mine.
The opportunities that I was given here in this job were pretty minimal because it was really up to teachers to invite me in. It was never like 'Rob, you're going to develop this curriculum and everyone is going to follow it', it was a little bit of hit and miss. Finally I was able to convince the head of middle school, so 6th grade till 8th grade to give me a little slot of time with all students. So that's a little slot of time which is 30 minutes, which is not much. So I would have a cohort of 16 students, for about 10 days, 30 minutes a day, which is about 5 hours, less if you calculate all sorts of things into it. So I had about 5 hours to develop into kids some kind of interests into programming.
So the feeling was never that they were going to become expert programmers, it was really to develop this interests in kids, and I was very interested in developing that interest for girls. The school has this robotics club and a pretty good Computer Science program in highschool, so getting those kids interested from an earlier age so that by the time they get to highschool they've got some context of programming was the goal of what I was doing. I started that by 'What would be a way to get the kids interested?', and as an artist myself I decided to approach it from the art side of things. I wanted to teach the language Processing.
I'm not a computer programmer myself, so I had to get myself up to speed, I found a Computer Science student who knew how to use Processing. So it was basically this idea

that you're going to learn Processing by watching these videos and then you're going to basically be given a task to create some type of interactive piece. It was very open-ended.

Theme: link between developing & maintaining students' interests, and open-endedness

I felt it was mildly successful, you were asking about doing any kind of documentation, I would do some surveys at the beginning of the class around what they knew about programming, what languages they liked, just to get a general sense. And I would do another survey at the end of would they do this kind of thing on their own, would they do it in a class. For the most part, I'd say 80% moved up in terms of interest. The ones that didn't mostly just stayed flat, but most kids moved from 'not interested' to 'kinda interested' or from 'very interested' to 'i'm going to continue doing this on my own'. So I was kinda in the right ballpark. But I also realised that the Processing language is kinda complex and too.. Maybe complicated for the 5 hours. So the kids that it really hit were the kids that already had some interest in that and I didn't think it would move any further. I also realised that I needed to start work with teachers to have them use these skills the kids were developing outside my class. So could they use these outside in their maths class or history class? So I started talking to some teachers, and got some interest, but they were mostly like 'we have our curriculum, I don't think we can make this work'. And then over several years, I started with Processing, and I said you can either do Processing or you can use Mbots (like a MakerBot, like a robot, I think it's from China, that uses the idea of Scratch, so you're using Scratch to then have robots move). I really wanted to move away from just staring at screens and get them, 'how can I get this to be doing things in a real world?'. I used that for a few years, I used the Apple product called Swift, and that one I felt was the most controlled. The kids didn't have much opportunity to get very open-ended, they really had to get through this gamified path. So I was playing around with different ideas.

Theme: The learning activity, building interest, takes priority over documentation, which may take some of the interest away. In addition, difficult for teachers to articulate what type of documentation would actually be useful - in absence of a promising like of documentation, the teachers prefer not to do it at all.

Around the same time I was also invited to teach programming at elementary class, so 5th year, and they gave me the whole year. Again, just a really small chunk of time, 30 min a week. But they kids really loved it. Basically 99% of students were really involved and interested. Again, that was much more open-ended, I would be like 'What do you want to make? Do you want to make a game or a story?', and I would give some paths to follow and .. again Scratch is so well-designed for exploration that I didn't have to do much teaching. I would be like 'watch these videos to learn how to do it', and kids really loved it and they really bought into it. So 2-3 years ago a colleague of mine had gone to a conference, and they were like 'You should look up this thing called SAM Labs, it was really interesting, and this guy Morten was there and he lives here in Portland and it was really cool, you should check it out.' So I went on the website, I checked it out, I was like 'this looks interesting, it looks a bit like LittleBits, but a little bit more sophisticated and a lot more expensive'. So part of my job to be trying new technologies and see how usable they are, and really I try not to get people to buy too much stuff, because people are buying a lot of things and they end up not really using them...it was at a time where people started using OzBots and the Sphero robot… and for me.. I've never been really that enamoured by robots. I was never that

interested in going down the robot route, I was more interested in art and creation. Something like a Sphero is so limited. It teaches programming and kids enjoy it but I felt it was limited in terms of of the scope it can reach, and what you can do with it.
So my colleague was like 'you really should check this out', so I ended up writing to Morten and he came in to do a demo for me. And then I was hooked right away. I saw the potential right away. Within 20 minutes we had sketched out an idea and basically built this little prototype of a glass of water that would let us know to drink more. And seeing that, that was enough for me. **The technology was simple enough to for kids very young up to adults, and they way it was structured and built was really open-ended for me to think about all the different ways it could be used. So that was really exciting to me.**

Theme: the open-ended ness a clear appeal for why teachers use SAM Labs, above other tools.

When comparing to LittleBits, the programming bits obviously brings it to this other level. LittleBits are so static. I tried for years to get kids interested in LittleBits from my very young children 5 or 6 of my own, to highschool, beyond a few projects I never felt it went anywhere. **But I was the potential in terms of programming to make almost anything**. So that was really exciting for me.
In the school I was given this grant to bring people into trying new technologies. A teacher approached me that had been teaching social studies in middle school for 7th graders, so 11-12 year olds, so they learnt about different cultures. The final project was the production of a film, and he approached me 'I really want to do something different, will you partner with me to do something new?' and I said 'well, I just got this grant, and I'm really interested in this technology SAM Labs which seems pretty cool. I had also watched this film called 'Most likely to succeed', that was making its rounds in the US. It's basically a film to explore a little bit the underpinnings of American education and where it all went wrong. It focuses on a school in San Diego called High Tech High, which is a series of schools now. There were a couple of teachers in that school, a physics & woodshop teacher and history a teacher who came together and they posed the question of 'why do cultures rise and fall?'. **And the students were studying history and how mechanics work, and they had to create these physical models of their own ideas. The kids had to propose an idea of why did they think cultures rise & fall, but then they had to place these gears, using pictures and cutters and laser cutters to show kind of metaphorically**. I was really inspired by this physical making of things.

Theme: Using SAM artefacts as metaphors for bigger abstract ideas an integral part of how the SAM blocks are used. Acknowledge this conceptual goal half of the appropriation model into the visualisations.

So I was like 'Why don't we do that'? Take a big open-ended question and gets kids to build their theory. And they would use the SAM Labs tools to do that. So our big question was 'How do new ideas change cultures?', and the students were studying ancient China, Japan, the Middle East and England. And they basically had to come up with a theory based on one idea. So one student was following the Magna Carta. And used SAM Labs to explain how Magna Carta changed peoples' ideas. And basically what they did was they used a servo and a button, and a light, and a slider. On the slider it would say a bunch of dates - 1300, 1400, 1500 and 1600, and you could move that slider to what date you wanted to point to.

And the button would connect to the servo and you could decide to point to the king, noble people, the working class or the poor. So you could say, in the 1300s, was the power of the kings going up, down or staying the same. And they used colors, so the lights would be the colors, the green going up, the red going down and yellow stay the same. So this very interactive piece.. And that was probably the most sophisticated of the group of kids. And those were all little pieces of a pie. And there were 6 pieces on the pie for England. And then there was a different story for each piece of the pie and every student had a different piece of the pie.. And our final exhibit, the parents came to the art gallery where all the projects were there. Some of the pieces had to be repaired whilst they were there, so there was lot of ongoing work going on there.
So that was my trajectory with SAM Labs.

ME: What is your criteria for evaluating these projects? Did you have an evaluation criteria for the project, and if so, what as it? So what's important to you that students do when they engage in these projects?

That's a good question. What I didn't mention is that part of the way in which we went about the project is that I had this 30 minute class. So before the students were engaged in this larger study of culture, I met with all the students in that grade and were basically taught how to use the mechanics of SAM Labs. I started off saying 'I want them, knowing that they are going into this project, I want them to have a basic understanding of how the block coding works, to have a basic understanding of all the different devices and what they do, and I also wanted them to have a level of problem-solving and exploration, that kind of freedom, their skills were built up enough that when they were free and it was time to start the project they would be like oh, if we want to make a gear we could use the servo combined with the motor.. So they knew enough, and they had enough context and schema of SAM Labs to artistically choose their pallet of things. But in terms of straight evaluation, I haven't really been required to do that. I didn't really document per say, I think starting off that project was really in those 3 categories: basic understanding of SAM, and breaking it down a little into a basic understanding of what a loop is, and an if statement is, and then to some degree for the more advance students what a variable is and how to use them. And then last year I did some similar projects but I paired with a science teacher. My personal evaluation tends to be around the programming concepts and the physical building of the pieces. I don't do any collection of very hard solid data, I have them for such a short time for 30 min.
I'm really interested in the work you're doing, because my projects haven't been long enough or deep enough to feel like I could do any strong evaluation of growth.

Theme: The type of evaluation teachers look for from the open-ended SAM projects - growth

Other than more qualitative things that I pick up in terms of how excited kids are. One thing that I did in terms of observation, for these kids in 7th grade, their evaluation of their understanding of their ideas they were putting forth as historians were much greater than the year before when they were making films. So before they would make for example a film about what happened in England, a piece of 5 min of film, and that never really proved their understanding of those ideas, but this project required them to think really metaphorically. So that's one of the areas I'm really curious about personally - the use of physical tools to help kids understand the physical world and really how can you use metaphors to make meaning. We had a student-teacher working in one of the classes, and her observing from the university was a little bit blown away by what these students were doing and thinking about in comparison to what other 7th graders were doing in other schools. **The depth of that question and exploring the physical make-up of these tools, and how do you take an idea and show it physically.**

ME: This shows you the implementation of 4 different students of the same axe behaviour. All of them started with this goal of having an axe on the board. This is the final implementation, the end product of this axe behaviour that these students implemented. With this limited info (don't know the students, you weren't there), if you were to rank them, what order would you put these students in?

You mean in terms of complexity?

Theme: when asked to evaluate SAM artefacts without a pre-specified criteria, teachers go-to criteria is complexity.

ME: Yeah.

To be honest I don't use the SAM Space very much, most of the work I've done is with the SAM workbench, so I don't always know what the symbols mean very well. What's the small than larger than symbol?

ME: That's the code module and it manipulates the value from the proximity sensor.

So for the one below that, they hit the pressure sensor, and then they have a hold.. Yeah. I'd say probably, my initial guess, the most complicated, the idea of the hold and thinking through the hold that's kinda of sophisticated, they're really thinking about the user and the consequences of something happening.
Probably 1 and 3 are most sophisticated, and then maybe I'd rank, I don't know between 2 and 4… they seem kind of equal to me, in terms of the code they are writing they seem similar.
1 and 3 are thinking about the user rather than just getting something to happen, so that seems a bit deeper.

ME: OK, so this just a stepping stone for the next visualisations. I really wanted to emphasise the process, rather than just a final product.

Visualisation 1:
OK, hm, so it's like they tried this, then they tried this, then they tried this...
That's really cool.

ME: Oh yeah, you think?

Yeah, definitely. So were you in the classroom, watching this, or were you the documentarian?

ME: Yes, exactly. I was there the whole time, but I also recorded these states in the SAM logs. I logged these states the students go through, to have a record of all the changes that the students make. But it made all the difference really to be there and put these changes in context.

This is really cool, this is really actually quite thrilling for me, because this is always what I'm really interested in is… one of the things I… **it really gets me thinking how I can talk to teachers about having kids document that process more clearly.** Which, especially kids using iPads at the end of the day, take a screenshot, do a little record of what they're thinking and what's going on.

Theme: teachers do look for ways of documenting these projects, and specifically the process

Do you also have, within this research, do you have the context within which… this is over time.. .were they key moments promoting them to rethink their work? So are they more like - theses are each lesson and what we focused on, or a stream of consciousness of what these students went through?

Theme: One of the questions for teachers is - what happened in the wider context to trigger x and y in the data? The need to complement data with the wider context., the limitation of any data source, and the mapping to lesson events to query the design, rather than intervene to 'correct' students.

ME: Mostly the latter. I do have digital journaling from SeeSaw. So there was some of that happening, but not fully, and not for all students. It worked for some students, but not for all. But that's a good point to analyse it from the perspective of what happened in each lesson, so what might have happened when to prompt certain actions?

Yeah, so this is really cool. I can imagine having a second layer of that (the lessons context), so that the teacher, the lessons that you can click on, oh here's the lesson for that day, for this particular section.

ME: Yeah, that's a good point. I think in an ideal world that would be better documented, but actually the lessons didn't always end up as planned. Also the students worked on different parts of the game at different times, so different things happened for different students at different times.

Yeah, this is really cool. I'm super excited.

ME: If you were to rank the students again, what order would you rank them in?

Yeah, OK. Remind me what the significance of the color is.

ME: <I explain>

What is the … so you've got the dates on the x axis, and what's the y axis again?

ME: <I explain - the different approaches>

That's really interesting, I totally changes… if I look at it that way, **it obviously completely changes my view on student 4.** My interpretation of that is that they were trying a bunch of different things, being more exploratory, possible being more inventive. I'd have to go back and look at student 4 individually, but yeah…

Theme: the visualisations change the teachers' perception of what the students did from looking solely at the end outcome. Not only students but also teachers can be end-product focused.

Student 3 continues to be… that was the one I was thinking was more sophisticated anyway, and it seems like they are more willing to try things that don't function. Oh this doesn't function, this doesn't function.. Whereas student 1 and 2, especially student 1 is .. they've got a few things and then just kinda stuck with it. Maybe they're already really good at this, and it was not so difficult because they already had a bunch of skills and it was kinda like they knew what they wanted, and they went for it, and they figured it out over time. But **I really love how you can start asking questions** about … **I really love the questions they <the visualisations> pose.. Like student 2, I wonder what happened at this juncture (after the first long valid attempt)**, .. oh, I got this thing working really well, what got them to try all these new things? So, it definitely opens up a lot of questions for me, about the students, and the process… that's really exciting to me.

Theme: teachers excited about the questions the visualisations prompt, rather than answers

This suddenly is making my brain go dum dum dum dum….
We're actually stating this project with Morten, we're putting together these SAM boxes, and we're thinking about what could we do to actually analyse their learning? This is a good drug for me.

ME: If you had this visual available for your students in your classroom, how would you use it?

Oh wow. How would I use them? I think for sure I would use it as a prompt for my own curiosity.. Especially if it was open-ended. One of the main things about these open-ended projects is that students go in all sorts of directions. So I was even more open-ended with my students this year, but it has to be either a piece of art, a prototype of some kind… so it's very open-ended, so students went in all sorts of directions. **So in terms of content, it would be very hard to track. But I think in process and experimentation in an open-ended environment… the connection between what is happening specifically in any given day, and the new information that is coming in would be really helpful**.

Theme: seeing what's happening with no filter/interpretation is helpful on open-ended contexts

So could I bring in some kind of new information, and see what happens. So I know on this particular day I brought in this new idea, but nobody took it. Or many people took it and it was potentially can be a game-changer in the type of lesson I present and the kind of information I presented.

I think it would be great as a tool for kids to go back and use it as their own visual. Look at their process and say ‘Oh yeah, I remember at the beginning of Nov I had this idea, and I’m gonna grab something from my journal’ and really be able to have these students- generated assessment of their own work I think would be really exciting. It’s something I’m really excited about, and kids hate it. Kids hate that kind of work, but I think when they can look at their own story, and they can generate a story that they can tell about their own story, I think that can be really powerful.

Theme: students to see their own data

I think the potential for this is really… I think it’s because it’s so individualised, and really visual. I’m a visual guy so these kind of visuals, I gravitate towards.

Theme: the individualised views are important

Visualisation 2:
ME: Ok, great, thanks awesome. The next visual is blocks and connections <I explain>
Do you get anything about their trial-and-error and if so what?

There’s a lot going on at first view. But again, clearly Student 3 was trying a lot and mixing and matching. And compared to Student 4, who had kept going back to use the same thing over and over again.
<he looks at blocks & connections AND approaches over time side by side>
It is really interesting to compare these two views. Now I’m even more confused, looking at both, because it does change what I thought. It looked like from here that they were trying all these things.. You have here <in approaches over time> when they go back to the same thing, but...well, maybe not. Let me compare student 2. This is interesting, this line, using the same thing for a long period of time.
Yeah, I mean, I think it’s helpful. I’d definitely like to take some time to compare these two views. **I can appreciate the level of complexity in their thinking and all the stuff they are trying out.**
Yeah, I was thinking suddenly, again going back, I can see myself going back to let’s say Oct 7th, and move it.. Visually that would be fascinating to see.

Session 2

I shared our conversation and some of the work you’ve been doing with my supervisor who’s the Director of Technology at the school, as well as, there’s a, we have some people on our team who are instructional couches, that support teacher professional development and things in that area. One particular teacher I have a close relationship with, we work a lot together, she’s a former mathematician and she’s very interested in research. So I expressed my excitement about the work you were doing.
One of the things I was wondering about and hearing about all of the things you are doing, what I said to her is I feel like your work and the way you are using technology, I said I don’t know all the details or the technology of how you’re doing all this kind of tracking, but I feel like the work you’re doing has implications for a larger work that she wants to be doing

specifically around assessment, and looking at the process of learning. The tool you are using and the methodology you are using in your study is compelling.

Theme: potential for use of the visualisations in assessment

ME: Yes, let's chat further. These are early prototypes, but the eventual intention is to fit somehow into the assessment of these projects more broadly. They are also very SAM specific, but I've tried to draw out generalities and methodological points applicable to other contexts.

I have a little bit of a question around the process you've gone through. So you were working in the classroom?

ME: Yes.

So let's talk about these 4 students. So were you really just focusing on the 4 of them over the project months and following closely what they were doing? Was the data that I was seeing your collection of data rather than the students sharing out their projects.

ME: I was there personally, because I wanted to get the context. But I didn't do the data collection directly myself, nor did the students, it was tracked in the SAM Labs back end. It wasn't done manually, and I was there to get the context, but I worked with the automatic collection of data with my knowledge of being there.
But there are different ways of getting this data: someone else recording it, it being recorded automatically via a tool (like SAM), or the students recording it. But the students' record is often incomplete / partial. They focus on some changes and not others. They record some stuff but not other. It varies widely, it can be challenging, especially at this micro level. And what I wanted was to have a full picture of all their approaches, which is why I used the automatically collected data paired with the digital journals of what the students felt it was relevant to document and the context of what happened in the classroom.

That actually is .. that's interesting to hear. Because I think what you're saying for me it's probably true as well. The constant documentation over that period of time would become somewhat monotonous for that period of time, you know, and if you can actually you can grab.. I didn't know that was a possibility. **I know a lot of education software are about tracking and figuring out where things are going. But I think that idea of being able to connect the visual piece and actually see what they did and how they did it it's… in terms of long term.. I guess it would have to be automated, to keep people sane.**

Theme: seeing what's happening with no filter/interpretation is helpful on open-ended contexts

ME: Yes, defo. I think there's definitely value in getting the students to do some of it...in terms of I guess the thinking process behind acknowleding the changes that they make, but it does depend on what level. And the intention with these was to have the full set, and the teacher and student probably wouldn't discuss every single change, but they might identify specific… oo this is interesting, I can't figure out why they did that, or.. Stuff like that. But the general principles is that in one way or another you get to collect these versions and

represent them. And there are benefits to the automatic methods, I think I showed you, you get to see how long they spend on things, which would be almost impossible to collect manually.
<I give the example of the Scratch journeys>

Visualisation 3 <kept versus discarded>:
ME: <I explain the visual logistically>

Rob: <Interested and excited, chuckles through the images, interested> Student two is throwing so much stuff that it goes off the page, is that what's going on there? Or why is it so flat?

ME: <I explain about the number which changes>

So with the other ones, let's take Student 1, two thirds into the process, they have certain stuff that they want to keep, and they just kept them all the time. They knew that, we like this, and we're going to keep going with this. That's so fascinating.

ME: So a bit like the previous ones, what do these tell you abut their trial-and-error process? It's really intriguing. It seems like student 1 and student 3, at least visually it looks somewhat similar. They had ups and downs and somewhere two thirds of the way in they had stuff that, OK, I like this, this is something I want to keep, I'll keep messing with some other things, but I'll keep this. Is that right, is each unit a block?

ME: <I clarify it's a connection between two blocks>

So they have 4 connections by the end. OK. So really looking at 1, and 3, in terms of what they're keeping and working on, they are similar. Student 2, it's really interesting, I'd love to delve into more and understand what's happened there in the process.
Actually Student 4 is slightly similar too, that they try stuff out and three quarter of the way through… Number 4 had some connections they kept the whole time, but again two thirds of the way through there is this jump up. That makes me wonder like.. Is there a deadline there, a lesson there, what was it that happened in the classroom at that point in time to spur on some of that finalisation?

ME: <I explain it's similar for code clubs> For this student, the deadline was definitely the end of the term where they needed to complete their board games.

That's fascinating to me, on a kind of human level as well. Of what's going on in our own processes as humans in trying to solve problems. At some point we make that commitment of one way or another, and it would be fascinating to see that, seeing that kind of thinking play out in different arenas. You're looking at this open-ended situation, is that a product of the open-ended ness, or is that just in our nature as humans. Would you see this in a more controlled lesson? Or are those controlled lessons more like following steps, so not experimenting as much, so would the data look very different? Use that to compare in different contexts.

ME: It was nice of me to observe this, because it's not like they find something that works and keep it, and get to it as soon as possible because it's open-ended. It's the opposite. Because it's open-ended, they only start building towards an end-product almost as late as they can. And they spend the rest of the time trying other stuff out. Which is quite nice.

The other thing that it makes me question, you said the initial idea she had, on the video, this 'off with his head', and on the back of that all of these students are using this chopping mechanism. O**n an external level, for me as a teacher it would be like 'oh, they're not really doing something super creative. They're taking my idea..and they're all taking my idea' but this seems to suggest, even when they are doing that, it promotes the idea that even when you're giving them an idea to go down, and it's an open-ended situation, they're still going to be using that creative, problem-solving, trial-and-error and then .. it's not just like, well, they just copied everybody and they're doing the same thing, so they're not really learning**.

Theme: the visualisations change the teachers' perception of what the students did from looking solely at the end outcome. Not only students but also teachers can be end-product focused.

ME: Yes, exactly. They very much appropriate it in their own way. They got inspired in terms of the end goal, but the experimentation of how to get there is still very much in their own remit. It's exactly the same goal, the same main idea of 'off with the player's piece', but they very much appropriated their own final ways of interpreting it.
And this is something it's easily observable in the classroom but I'm not able to show it easily from the data.. They would actually collaborate organically and go from one desk to another, they were trying to move it ideally on the pizza board in terms of direction, etc. so they collaborated in terms of the mechanics, but they very much wanted to have they own kind of implementation to be different from the others.

Questions about the students: 1) Is there a mixture of gender in this? 2) How did you choose what students to start following?

ME: <I explain the context>

I'd be really interested to see, is there a difference in that process between girls and boys. That's really interesting to me working in a pre-school and high-school. So in pre-schools, I was teaching them to use Scratch junior, and I also offered an after-lunch club, and that was really primarily attended by girls.
So one thing that got me thinking about the differences between girls and boys, girls seem to be much more character driven, and boys seem to be much more plot driven in terms of what they are creating. For example in Scratch Junior, girls were really interested in the story aspects, create scenarios about relationships, which I don't think it's something new necessarily, but it was interesting to see how their way of being in the world was expressed artistically and through Scratch coding to continue this exploration of people talking together and what they created was much more about interaction between characters. What the boys were creating often was much more about doing something. So the geared towards much more of a race or some kind of a sports thing. There would be interaction between characters, but was riving them was much more 'we want them to do this thing'. And the girls

were like ‘we want them to interact in this way’. So looking at the graph you have here, I wonder if the same kind of thing would happen in terms of how, is that same process of creativity in those two ways of approaching it. Are they going to look the same? And also comparing the older kids, the 12 years old, that kind of continued on. I would allow people to work in groups of 2, and it tended to be girls would group with girls and boys would group with boys. Girls would continue to create things that would be around interaction, and boys would create things that would go do things. That’s something I’ve always been interested in and I’m very curious about.

ME: One thing that I found with these visualisations in talking to multiple teachers is that the same aspects come out (trial and error, etc.), but the decisions and the conclusions around those same aspects can be quite different from teacher to teacher. So this idea of showing complexity, and showing it in a way that enables decisions but not necessarily takes them, is something that is really interesting to me.

That’s great. I think that’s what’s exciting to me, because I feel the same way. In both those two areas I feel.. I’m always very wary of the direction of AI type of things, these kind of very formulaic ways of looking at humans, and using data to march people along. My wife was also an educator, just recently was meeting with some former colleagues and was talking about in the district she used to work at they have these things, people would come into the teachers’ classrooms and they would be like ‘You need to have, be on this page, at this time, with this on the wall..’ and there’s a real danger of using data to move towards this kind of robotic view of humanity. **So I’m inspired by your take in the possibility of laying this thing out as an opportunity for conversation, and asking deeper questions, rather than giving answers.** Like this conversation, I don’t know these students, but I imagine if you had, you probably had these conversation with that teacher, that she would probably start thinking about her students in totally different ways, providing a totally different type of support than if that, those numbers were crunched and said ‘No, student 1 should do this now, because they did this’..

Theme: teachers excited about the questions the visualisations prompt, rather than answers

I’d love to invite you to this project we’re doing this Morten. I’d like to invite you to the Slack channels where we are planning that. We have 10 teachers and about 200 students that are going t o be part of this project. I’m going to introduce these visualisations before we even start learning about SAM Labs. The kind of questions that you are playing with would be really interesting to pose before we start the work together. Maybe invite you on a Zoom call that you could talk more about your research and what you’re learning about. There’s this large group of teachers, there’s many that I think would be interested and there’s a few in particular that they’d go crazy about this stuff.
What I think it’s great about these, what you have already, is it presents the opportunity to talk about these things. What you have already, for me at least, and the way you presented it, what do you think is going on here, and how would you rate / categorise these students, those open-ended questions that prompts them, even just using those first 3 or 4 slides and spend an hour and talk about this, and what are the implications for what we’re doing this year.

Visualisation 4 <kept versus discarded with validity>:

The density is fine. I think that's great. That brings it to another level of really understanding… looking at 3, and how much was discarded, none of those things worked. So they clearly spent many days doing things that technically were not able to be done. That person, I keep coming back to Student 3, maybe this marker of this person who has a lot of resilience. If you spend that many days with failed failed failed, there's a level of curiosity and resilience that's interesting.

Theme: prompts teachers to think of resilience, perseverance, curiosity, comfort with error

ME: Yes, it's interesting, I actually have a few of Student's 3 projects and he actually does very little that works, until the end. A lot of his projects look the same in terms of .. he's almost not interested in anything that he knows already, and he's always looking at 'these things I've never tried, does it work?' Which ends up in a lot of error, which he's very comfortable with.

Theme: prompts teachers to think of resilience, perseverance, curiosity, comfort with error

Yeah, and I start wondering, is he the kind of kid that.. I think about my son, who's 12, and he has never been compelled by really what the teachers wanted him to do. He's not a kid that is ever moved or that ever feels he needs to please the teacher. So is this particular student like 'I'm just going to follow my own path, and be a little bit out there, and be like 'I don't care, I'm going to do this other thing…'. Again, to me this is very interesting from a human nature perspective, what does this say about this particular child?
And student 2 is really interesting, he spends most of his time on these things that work, and right at the very end throws all of that away and puts something in that isn't working. That's really interesting, at some point, clearly something happened that day that cause that students to… I know you mentioned that some of the data was maybe kind of hard to decipher or something but it's like, 'what's going on there?'.
That's brilliant! I mean, that… this whole process is just brilliant.. I mean I can appreciate that .. you know, you know those students, so you can tell the story, and I think the story itself is what becomes so valuable. Does this data really tells the story, and we need to fill in the human side. I can make all sorts of guess, but please, tell me about these kids.

Theme: the visualisations tell a story, and inspire a desire to know more about the story, more details, more questions.
ME: also, a good way of presenting the visualisations in my thesis as a story

I'm the type of person, I live a lot in the '3000 feet' as they say, look at the big picture things. If I'm not compelled by the big picture, I don't look into the details. But this, definitely, I would go back, I'd be curious to look at what they actually physically did, go back and look at what they actually did. I'm interested in that from my own perspective, for my own learning of how to use SAM Labs in ways that are .. I'm still learning and I'm in that process. As I said I'm not a programmer..
But then looking at Student 4, I'd want to go back and look at.. What are all those things that they did that didn't work, and I won't do those things. It's great, really interesting stuff.
Yeah, just looking at student 4, there's a lot of attempts, and a lot of successes 'this does work, I don't want it, this does work, I don't want it, this does work, I don't want it…'

Theme: prompts teachers to think of resilience, perseverance, curiosity, comfort with error

Visualisation 5 <component-specific circuits>:
I'm kind of stumped by what this particular… I guess looking at student 4, the width of the line shows that they kept going back to that particular circuit.. So that's interesting.
Let's say student 3 again, to me it seems like it has the least..
The question if bring up for me, is there some level of efficiency that allows student 3 to do what the others aren't. Clearly the student 3, the pressure to motor, that's a very efficient movement - just this to that. But it's not potentially sophisticated in terms of looking above it, at what student 1 is trying to do. Either student 1 is trying to do much more complicated things in terms of what their users should be experiencing, versus student 3 who might be like 'well, I know how to do this'...
That's actually one of the things that.. I don't know why I attach to student 3 so much. I feel like I know that student. As a teacher, and how you described him, he's kind of sometimes the kind of student that is sometimes very self-focused. So not as willing to take input from others, like you suggested, and also sometimes approaches things as 'i know how to do this already, so why change it?' I want this, and I'm going to do this'
And Student 1 might be like 'Oh, I'm going to try different things out, and I want the experience for the user to be.. Something more sophisticated.'
Those are the kind of things it compels me to wonder about, in terms of the approach that those differences mean and exploring.

I'm just wondering, **for my own metacognition here**, does this speak to what I just mentioned earlier - my ability to think about and analyse data on a larger scale. If I see the whole picture, I can start really quickly starting to make inferences. You show me one little piece of data, and suddenly I'm .. huh? For me, all the other visuals you were showing me were like 'wow, these all make sense and they build on each other. And then I say this and I suddenly was like 'huh'? Even I can tell I'm less compelled by this than I was by the others because even as a story, I'm a person that - as a teacher and a student, I'm compelled by the larger story rather than the page or the chapter. With this visualisation, I'm like.. Show me more examples, and then I can start to make inferences.

Theme: teachers see potential for their own metacognitive use and professional development

What they technically choose to use <the specific SAM Labs blocks> is it a compelling enough as part of the larger narrative of the learning? Does it matter enough? If they choose a button over a pressure sensor? Of if they use an infrared sensor over the pressure sensor? Those might be a little bit more random.
But it might be relevant in terms of thinking about the type of sensors that kids make sense of. There's definitely sensors in my kit that my kids never use. I try to get kids to use the tilt sensor, I have a few of them but I never bought many. Students never seem to be drawn to it. But it doesn't make me think 'oh, how can I get kids to use it maybe they'll discover something interesting'. It's just like 'maybe it's just not as a compelling thing to use'.
It makes me think, I could do something like 'make something that has the tilt sensor in'. But my interest would not be, 'well, what did you do with the tilt sensor, it would be more the type

of experimentation that you have graphed, like 'what was the process once they did use it, rather than the tilt sensor itself'.

ME: Yeah, maybe components isn't such a good thing to section by.

ME: How does what you've seen in the visuals compare to what you expect your students' experimentation to look like?

I think it pretty well matches the types of different learners that I have. When I start seeing the data and think more and more I started seeing certain types of students. Going back to Student 3, but also 2 and 4.. The school I'm in doesn't allow for the amount of experimentation and open-ended ness I'd like to see. So for many, my class was a creative outlet. My 30 minutes lessons were before lunch, and what told me that the kids were interested was that they'd keep working into their lunch breaks. Their friends from other classes would come and get them and they'd still be working. Once they've figured out the technical skills of how to use the tools, I think they were much more willing to experiment over long periods of time. And there were kids that a third of way through, they'd be done, and you'd need to come in and find new challenges for them. I think I can find those 4 students in my class for sure.

Theme: teachers are able to identify the type of students they see in their classroom in the visualisations

One of the things, when I was working with 10-11 year olds doing Scratch, at the school I'm at, I don't see many students asking me that question 'Can I try this?' There's enough of a culture in the school that allows them to do that, that you don't have to ask for permission. When I first started teaching this programming class 6 years ago, it was a French class, and the French teacher was there when I was teaching my class. This was before SAM, when I was doing robots or Processing. And I notice some kids they would go sit by the wall. And I knew that by the time they start sitting on the wall, they are not doing programming anymore, they're doing something else. So I would start having setup things like 'you can't sit against the wall', or I would go sit next to them and they would close their screen, and all those kinds of uncomfortable things. And I noticed for those students sitting against the wall that they would have hit a wall when they didn't know what to do. And rather than coming to me and ask 'I don't know how to do this, and how do I do this', instead they would turn off and stop moving forward. I mentioned this to the French teacher, can you help me with this? I didn't have much experience with middle school. And she said 'yeah, you know, that is always an issue we always have to deal with in middle school, kids having to advocate for themselves. Her sense was that kids at middle school, because it's a private school, there's a pressure to always be high end, that students don't want to show they don't know how to do something. So that is more the kind of thing that would happen. If I was to look at a graph, and the kids stopped, they would start experimenting and then they would do the same and then stop. So to me it's that, how can you develop a sense of curiosity? I share all that to say, once I started doing SAM Labs, I stopped seeing that to that degree. Maybe there'd be 2 or 3, but they wouldn't even start engaging from the beginning. But the SAM Labs itself allowed for this playfulness that the other computational tools didn't. How do I, when I get to that sticky point, what are the kind of things that will bring about this curiosity?

Theme: Difficult mindset to instill / encourage / nurture

I mentioned to you that I started this non-profit, it's all about tinkering and design and thinking. So I learnt a lot about these things outside the classroom. What we noticed about the kids that were coming was that about a third of the kids, would come in, and delve straight in and be all in for the whole week. A third of the students would come in and start all in, but about half way / third way of the way through they would start petering out. And need a little boost of a one-on-one with me. Some kind of intervention. And a third would just drop out from the start. But the excuse these students would often give was that they are 'bored'. And when I started digging into that 'bored' piece, they weren't bored. They had had a fight with somebody, there was something emotional, there was a multitude of things that were clear it wasn't boredom. So what we started doing was, at the beginning of camp, we start by telling them 'you're one of these people. At some point, you'll probably say 'i'm bored', or 'i don't like this', but what's probably going on is one of these things…. So if at some point you stop and start saying 'im bored', i'll probably start asking you questions about these things. And it did start changing the way the kids were, because they did start thinking about their process a bit more. So it makes me wonder about taking this data and then letting the kids think about it also. What if kids saw it and talked about their own data?

Theme: potential of awareness of what happens, and preparation for it, rather than intervention

Resources recommended:
http://agencybydesign.org/explore-the-framework
https://edscoop.com/k8-coding-education-integrated-core-standards/
https://issuu.com/etchongkong/docs/book_of_crazy_cool_projects_digital

Comments from Slack:
'The thing that has been so exciting and transformational about what has been happening is that the coding really has moved into the background of the direction of the project but stays central to the completion of the project. They aren't programming for the sake of learning to program, they are programming because they want their vehicle to move in interesting ways, stop at a wall, pick things up, etc.'

'I think a key thing is having the kids work in pairs, and then having lots of opportunities to share out both challenges and their discoveries. Three are usually going to be some kids that can figure things out. I think the greatest 'lesson' that teachers need to think about is that it is OK not to know what they are doing. It is an exploration WITH the kids. They can rely on each other to solve problems tat come up. I met with a high school teacher at OES today who was a chemistry teacher and was asked to take on an engineering elective with Juniors and Seniors. She didn't have any CAD experience but approached it as a challenge WITH the students. Such a great attitude.

'We need to capture your 'planning process' (from a teacher's perspective) to help kids organise. Scaffolding this is a must.

<The teacher went through several iterations of the copernicus model to have something as an example to present to students. He uploads 3 versions of it to Slack (see Oct 31st 2018 posts). He then comments on his ideation process>:

It's been a lot of fun to conceptualise and build. I wanted to include a variety of devices (input and output) to give the kids some ideas of what is possible. I think one of the really important parts is that the making of the physical model really forced me to consider the content in a new way.
It got me thinking about how ideas build over time. The early creator (copernicus) didn't just set this thing rolling. It was a good 90 years before proof could come and THAT needed to include a new idea (the telescope) to push it along. And then the mathematical inventions by Newton really helped to sway people. New ideas NEED other ideas to manifest into something that really is society changing.

I've been wrestling with content too. Noodling with you guys made me realize I need to coach kids to think about the deeper issues related to their topics. Those conversations are happening at a deeper, more thoughtful level than in the past.

The pieces for my design are all ready to go. I also cut other pieces labelled to signify they are testers for rough work.
Paul: Awesome, so cool to see the infrastructure being built. And, the idea of practice piece is one that is brilliant for middle school students.

P: "Nice! Hope for an all group demo tomorrow around 11:30. 7th graders like to see what's possible, then go beyond. **We need to empathise the iterative part of your play. Kids aren't used to that being the task. Having no recipe, just ingredients, is scary to many of them."**
A: "I can show them all the steps I took"
P: "With emphasis on one thing leading to another. The silliness of the brush is cool, too. There is enough time for them to play. And they are reluctant."
A: "Yes. I can walk them through my process"
P: "Showing that process and the thinking is so key!"

So this weeek we started with a new batch of students. I had them watch all 4 of M's SamLabs Blockly videos. From there I wanted them to fill out a quick google form that explained in their own words each concept. From there I added the two vehicle creation challenges that the 7th and 8th graders were both given. What ended up happening is some students started to ask if they could test out other devices along side the RGB and Light Sensors that I gave them to use with the videos. From there they started to ask more questions (Could I create a police light and a siren?). All the kids were originally doing this work solo. But as they started experimenting they started to share their ideas with others and then borrowing each others' ideas. Today, on our 5th day, there was a group of 8 boys all working together on one project. They were making a police car with a snowplow. The various tasks were all spread out. Some kids worked on the lights, some worked on the steering controls, some worked on the buzzers, etc. This was all completely organic. And when P announced clean up before munch no one wanted to leave. A good sign.

While that was happening all the girls were working alone or in pairs on their own experiments and questions. One of the girls left with a big smile on her face. “I just finished 3 of my own programs”. They were all around the design of a rainbow function for the RGB. I spent a good chunk of the 30 minutes with one girl who wanted to figure out how to turn a light on and off with the same button. **I didn’t know how to do it but we drew our thoughts out on the white table as we ‘talked’ through what she wanted to happen.** After several tests we finally figured it out together. **It was an exciting moment when it worked the way she had imagined.** A big high five followed and she shared with another student who had a similar question It helped that I had some sense of a direction but she did ask if we should be using a variable. What I really enjoyed was that we solved it together. I was really curious and wanted to know and was just as excited when we figured it out together. I think that is a good model for teachers. I often say to the kids that I have no idea how to do it but I bet that we could figure it out together.

What I have been really enjoying about this process is that we did a little front loading so they had some tools to make bigger leaps than just giving them the challenge of hte vehicle up front. I think especially for MS students its helpful to give them the tools to feel successful. And while many of the kids did start moving to a vehicle creation anyway, they leapfrogged their understanding by having watched the videos. And they were much more creative in asking their own questions and exploring things that interest them. While we still did have the vehicle challenge for them if we need that to fall back on (for kids who might not have their own questions), I think they are now personally very bought in and being personally creative.

Teacher B

I liked that the second student <in the context video> was talking about this sword as a test. **So already they are thinking iteratively, like ‘I’ve got to test that, and then if it works I’m going to move onto the next step.’ That was kinda cool, the second student did that specifically.**

Theme: Teachers value iterations, where students display intentional ways of testing stuff out, of trying things out, setting things up to test them.

ME: What is your general evaluation criteria for open-ended projects, what is important to you that the students engage with?

For us, we’ve been using the design process, and for us it really is about the journey. I think the kids are having a hard time understanding, these are 14 year olds so proper students, **that we really don’t care if in the end your project doesn’t work. We care about did you document everything up to that point? Did you see where things went wrong and how you could fix them and slowly meander your way to the final goal**, even if the final goal is maybe a few steps away. That was the most important part. **And it’s hard. I think the**

kids are used to having something that works, and if it doesn't work, they don't know what to do next. So I think that's kind of, that's the biggest thing. **For us it's about documentation and re-visiting what you've done before, and making decisions based on previous experience.** That works for any project, that's universal, that works for an essay, for a science project, for any piece of work.
It's funny that you mention that, cause we're working with our science department as well, they're talking about energy transfer. How do you create something like that, and how do you document that? So he's looking at the same thing, are you applying knowledge from before, are you really thinking about your process? That's the key here. We're trying to use these ideas that are not just applicable to computer science, but to any project.

ME: Do you find it hard with this idea with testing and it going wrong being able to fix it? Some students struggled without heavy guidance? Do you encounter that and how do you deal with it?

Yeah, we have the same spectrum. There are some who are go go go but don't know where they are going, so they need some direction. And there are also those students who need a lot of guidance. As a teacher it's something that I've encountered a lot, encountered this difficulty many times. For us, the best way to do this is get them to review their previous work. And if you don't have any of that, that's difficult. Show what you did before, and we'll go from there. But it's a tough sell. Some are more comfortable… also **the way our education system works is very prescribed, there aren't many open questions**.. I don't know when you're going to be done.. And even when you think you're done, there will be another thing. And kids have a hard time understanding that.

In middle school, we have a scale: not meeting expectations, meeting expectations, exceeding expectations and going above and beyond. And to go above and beyond, I'm not going to put that there. Because if I do, it's very prescriptive. Whereas if I say, I will know it when I see it, and not just me, but your peers to. And not just more work, but 'I can't believe you did this!' And it worked, because no matter what level of prescription you give to the students, they will try to hit that. So we're giving them the prescription for the requirements, and then let them go beyond that as much as they choose to. And that approach has helped to rein in those high achievers that want to show how much they can do, as opposed to just for the fun of doing it. So it's been really good doing it that way. That seems to work well with these open-ended questions where you have the 'this is what you have to do' part, now go. The teacher kinda did that in the context video - these are the boundaries within which you work in, now go!
But it's hard, because some students do have a really hard time to find their own work problem. But some kids don't have the imagination or drive to do it. Some kids don't know where to start, it's too wide, and for others that checklist is missing.

Visualisation 1:
<I explain the blocks.> How would you rank the final implementations?

There's some that are very simple - 2 & 4, but 4 implemented 3 times. 1 has a choice, which might show a little more ingenuity in terms of coding. We see some conditions built in for students 2 and 4. I would say student 1 has the most intricate type of implementation, more complicated… whether that's the best ting to do for the game that's a different question, and

we'd need to look separately at that. The simplest is student 2, then student 4. But then student 1 has the most complex because of the condition.
Whether or not that's how I want I want to rank their process, that's different. Based on the end result simplicity versus complexity, that's how I would rank it, and that's all I can get from this picture.

Theme: recognition between discrepancy of evaluation - the mastery of coding display versus fit for purpose design.. Which could be different.

Visualisation 2:
<I explain what is shown>
Got it, right, so it's in chronological order, I tried this first, then this, then this. Right, got it. OK, so this is how Student 1 was progressing. So they had the filter on there, then they took it off 'that's not going to work', then they had a decision to be made there. So there's a filter, a delay, a code module… So at this point Student 1 has the implementation that Student 3 did. *<It's true - great observation - the third attempt from Nicholas is Arthur's final design, without the code>*
So this is pressure, proximity, proximity, and then here, OK they put in the code, and they decide to do away without the filter, and leave the code. This final implementation is what you want, because it manipulates the thresholds well. Got it, good. See, I like that, because now I can actually see the progression, see the different trial-and-error, that's easier .. the kid wouldn't have to worry about documenting this. It's just done by itself.

OK, so let's rank them again.. Let's look at student 2 again because student 2 was the simplest, so we've got this together, basically they're just trying thing out. He goes back to what he's previously tried, this is good, you know, this didn't work so let's me go back to previous implementation that did. This is good.
<he goes through some of the changes between blocks> OK, he's tried this, that, the proximity, the slider, the toggle, etc. <he spends time understanding the approaches>
It's weird, it seems like the student is progressing well, and here with the slider, he did something totally different. Which is odd. Maybe they wanted to start from scratch? Maybe this is where it would be great to talk to the student and say 'what were you thinking at that point in time?' OK then then go back, and then they implement their final thing.
So I'm glad that he went back. You can see a nice progression here. Even if it was a simple one. Clearly for this student it was difficult to put things together, and I guess maybe that can be seen, when he goes back to the same line, he's doing the same thing again, so we're seeing that kind of progression. So that would be something good to look at. In terms of progression, I like it.

Equally, I would still rank them <student 3> the same way as the first student, student number 1.
Student 3, there's a lot of stuff going on. He got stuck on… really got something complicated going on. So we've got the originally... OK great, I like that they start with that, go with the basics here. We've got that, the toggle, that worked...that's a choice there. Hm, but they didn't stick with that. That looks like student 1. But they weren't happy with this. OK and now he's experimenting, and it takes them a long time to figure this out cause nothing seems to work. OK and that's a different approach at the end. They have the sensor only at the start, and he adds it in at the end, but in the rest of it he's using the button. So he only goes back

to the sensor when he knows the rest of it is working, and they know that their implementation works properly. That's an interesting way to do it. OK cool. Wow here, you can really see the progression. I know that they kind of fell down the rabbit hole here <where student 3 has a lot of failed attempts> with just experimenting stuff, but that seems to be working well.

OK next one. OK just experimenting.. Ok he's got 2 buttons here.. And they go back and forth a bit… So again looking at the progression here I would say that this student is doing the least amount of exploring, just kind of hacked around a little bit. Even if they implemented the same as student 2, I would say that student 2 was much more engaged in trying to figure out stuff. Just off the top of my head, just looking at them. So I would rank student 4 lowest. There's no real plan here.

Theme: identifying opportunities to speak to students
Theme 2: the teachers see multiple attempts as progression

Visualisation 2: blocks and connections
<I explain the visual>

Yeah, well look at it again. So if we look back at what I said, student 4 just .. the classic definition of insanity, doing the same thing over an over again expecting a different result. Not that the student was doing that, but it looked like they were kind of stuck. They were stuck in what they wanted to do and didn't explore other things. Whereas student 2 there's a lot less implementation, very easy progression, but student 4, a lot of mucking around here. But here we can see clearly that there was a lot more implementation or exploration from students 1,2,3 compared with student 4. That's my take on it. That's a different way of looking at it, that thick line going back and forther, which means trying those things out. OK, we know that works, or doesn't .. so explore something else.

Visualisation 3: kept versus discarded
<I explain the visual>

Wow. OK, Interesting, yeah. OK so here, again, I know that we're looking at volume, but this visual looks nice cause you can maybe do a comparison of a percentage perhaps, how much blue compared to orange. 1,2,3 they discard a lot of stuff, they try a lot of avenues, which didn't work, fine great, but student 4 seems to be.. 50 / 50. That's a 1 to 1 ratio. Let's call it implementation ratio, if it's 100% or more it's not good. You want to look at below 100%, at least. **Cause it means you're discarding more than you're trying.** It could be that you latch on to something really quickly and you get it. It could be by chance you end up being lucky you end up with exactly what you want. Student 2 has the smallest implementation percentage but they keep very little. Student 3 too. But student 4 seemed to go back and forth. Maybe visual, but maybe even have some numbers of this one, or maybe a percentage.

And again you can notice that in terms of the volume, a lot less time it took student 1 to get to this point than any of these students (2,3,4). Student 1 was .. they knew what they were doing. Student 2 struggled but got there. Student 4 took the longer time to do something. So in terms of how much time it took them to implement something, it goes 1,2,3,4. That's an easy one to see from this visual.

Visualisation 4: kept versus discarded with validity

Whoa!! That's a lot. It's hard to read. I'm having a hard time seeing the information from the previous visualisation in this one. This one ends up being more confusing. Clearly might be useful for something things, but if we're looking for quick snapshots, visualisation 3 is much easier to read.

ME: Compared with the type of insights you might get in an open-ended coding project, how might these visualisations might add or complement what you might observe or ask students to document?

If I didn't have to worry about students documenting, if I didn't require them to document, this would be prefect. Because they're not used to it, it has to be a habit. And I think this is just one of those things, the type of project where there's not a lot of commenting going on. **Were's seeing where the thought processes,** kind'of, but even taking notes I find that is difficult. I think **I would still want to ask and confirm my suspicions. I kind of put together a narrative of the students, but I could be way off.** There's a lot of things that will fall through the gaps. But as an initial first look, I think this provides a really nice view. At the same time, I think I would show this to the students, and say 'look, I want to try .. I don't want to…' I don't want kids to put things together just to have a better graph. This might be an issue with using this as an assessment tool. But as a diagnosis tool, I think it's a great thing. It's really interesting, especially since it keeps track of those connections, where things worked, visualisation 2 is my favourite - 2 and 4 (approaches & kept vs discarded). 3 is.. Good, but it has to be super blatant. But 2 is great, cause you get a full circuit if you want, the implementation, the circuits that they've tried. That's my short answer.

ME: If these were available to you, how might you use them in the classroom?
Do you think you would use these with children in the sense of 'What did you do there?' and 'Why did you do this?', or would it be more detrimental because they will be looking towards the perfect graph?

For middle school students I'm going to assume best intentions, cause they're not machiavelic, they're 12,13,14. Especially if they are in an environment where we're about the learning and the process, and not the end result, then I think that that will eliminate that possibility and I wouldn't have to worry about it. Especially if I don't use it as an assessment tool but as a way of looking at kind of the overall. And it could mean that hey, you know what, in the ideation portion of the design process you're still at the development stage. That could show up, like it did for student number 4 for example. They didn't see a lot of trying things out. That's good, so maybe hey, student 4 needs to try things out a little bit more, or hey, maybe he needs to step away and go talk to your fellow students over there and get some ideas. Or just take a break, you know, I find that even getting students to something else, something menial over there for 10 minutes and then coming back to their tasks might give the brain a bit of a rest. Because you get stuck in that rut of ideas and you can get out. But generally if you nurture the students in an environment where we're all about the learning and the process, then those type of tools really work. If when you try to use them as an assessment tool, say 'you're going to be graded by this graph', then they go 'i'd better make that graph look good'. So yeah, that's a way to use this type of thing.

Theme: teachers often separate between learning and end result

This would complement a type of diary, or journal. Jon and I are still struggling to do that. Not just in programming, but in the deign class in general. Trying to get students to reflect back on what they tried, because that's the key to getting them to understand where they went wrong and what not. For 11,12,13 years old it's definitely a doable thing, especially if it's part of their learning process.

I would be nice, having seen these, having the graphs, going to the students and going 'hey, tell me about this and that..'.. That conversation piece is always going to be necessary. And documentation is even better. Nowadays with the students where they have SeeSaw, they have computers, take snapshots, take a video. We've also eased restrictions in terms of the format of documenting.. I wasn't seeing it enough. Maybe I wasn't aware, but we need to find a way for them to document chronologically but also in an easier format. I don't know. We haven't figured that out. Atm we're telling them to do it in Google Slides. It's easy to embed videos and photos. But they also try to cram it all in one slide. So we're still working on it.

Theme: getting students' side of the story

So these visualisations would be a great addition. But I find that, even for Jon and I, we have all these great diagnostic tools, we just have to use them judiciously. Otherwise we end up doing so much diagnostics, that we end up getting lost in process. So doing that, interviews, and also just making sure students know that it's continuous. I want to look at your documentation next week. And probably 3 / 5 weeks from now. Rather than a one-off snapshot. Otherwise you end up at the end, and it didn't really help them, we have to look at them as we go on.

Theme: embedding the awareness and the valuing of the process throughout the project.

Teacher C

I think that if this was the teachers' first time of implementing such a project that's great, because I think these type of projects are needed in schools to be providing students with these type of open-ended opportunities, with something in which they are expects to include these interactive components within the board game. Did she provide students with a rubric of what to include in the game?
I sometimes find that when providing students with ideas of what to include it will narrow their ability to be creative in the process of what they might develop, because all of a sudden they all think that that is the only way of creating something. So everyone in the class will start creating or altering the same thing.

ME: No, not really a rubric. Just this specification video.

So, throughout the design process, obviously they had the planning stage at the beginning, and did she provide them with time to do some research on other existing games, etc?

ME: Yes, there were a couple of lessons at the beginning to research existing ideas. The other thing she did was try to encourage students to record the changes the students went through. What changed from one lesson to another in their plan, how and why. That worked to some extent .. but sometimes they did, sometimes they didn't, sometimes they ran out of time. They used SeeSaw.

Were the peers giving each other feedback as they made changes along the way?

ME: Yes, to some extent, the teacher made time for each student to present their own project to the others, with time for the others to ask questions and give feedback, and comment on SeeSaw.

OK, I like that they got to collaborate that way, even if they engaged in the projects individually. I like that she had time for them to document their changes along the way. I know that for my own students they do not always enjoy the reflection aspect of it. But if I provide options besides just writing, like reporting the changes and talk about it along the way, then I see more responses from students that really engage in the process but might be more reluctant to document. So I like that she allowed them to take pictures etc along the way. And I like that she focused on the changes to the project too. I think those things are really useful. Seems like she had a lot of good components to it for a first projects.
The idea for the project was open-ended, but I feel like there are ways to develop those 21st century thinking skills a little bit more and to actively work through the design process a little bit more. For example I think it's important to strategically share with students the design process. I think it would have been good for her to being in someone who is already an engineer, who designs things. **Because as soon as you collaborate with someone who does it for a living, you realise the value of trial-and-error. You realise that's the most important part that you're working through.** I think that when students get to make real connections with experts in the field they can take that and apply that to their own project they are working on. My recommendation for her in the future would be that she spends more time at the beginning of the project building the background piece for the students, as far as, like maybe bring in an expert who is in that field, and getting their interest and having them talk to the students about something that they've created or designs. And having the students really jump into this brainstorming activity and sharing a guided rubric that they know that 'look at your plans for your project, do you have these things?', and then having the students to collaborate in grounds so that they take their ideas and modify their plans to make it better for the whole group.
There's value in working through the process, but we also want students to have a visual of what the engineering design process is. And allowing the students to realise which piece they're working on along the way. When my students present, they have to practice taking thorugh everything they did, and present in terms of the design process. S**o they have to create slides and take me through the stages of the design process, so these are the initial sketches, and then after we talked about it this is what we came up with, this was our prototype, this is what happened when we tried it, this is how we changed it, and this is where we are now. The students are not just saying 'I created this, this is what I made', but 'I worked through this process. Here is step by step how I did it.'**
In SeeSaw, it's great that they are recoding their changes, but I almost think there should be a template with the design process that breaks it apart. **They're creating this presentation**

knowing that at the end of the project they will share with everyone and know that 'They don't want to know what I made, they want to know the process behind how I created this, they want to know about my journey'.

Visualisation 1: end graphs
<no questions about the criteria, assumes simplicity / complexity immediately>
It seems like the simplest one is probably number 2, I think they probably had a very straightforward solution to the problem they had. I don't really know if that student had to go through a lot of revisions in the process of developing that strategy.
I feel like 2 and 4 are very similar in terms of being at the lower end of the process. Yes 4 wanted to have it three times, but it's still very straightforward **in terms of the process to get to that point.** I feel like 1 and 3 are complex in their thinking. 1 might be a little more complex than 3, I feel like 1 and 3 probably went through a lot of work in their process, the process of trying to figure things out. I feel like 1 and 3 probably started out where 2 and 4 are, as their finished part. They probably started there, and then they like, no, I want to make it more like this, what else can I do.

Theme: even for teachers who clearly acknowledge the necessity of the process, their judgment of the final graphs don't reflect it. Judging solely by the end result still pushes the teachers to judge by what they see, despite their acknowledgment of the process earlier on. Conclusion: we naturally judge by the data we have available, but even when we know this doesn't show the full picture. In fact, Jessica comments specifically on the process of getting to that end result, without having any information on it!!

Visualisation 2: approaches over time - each bar represents a different, completed draft, of their axe implementation.

I think it shows the process, I think it shows their revision of changes. For example student no 1, you can see their design here is very simplistic compared with what they ended up in their final version. And you can see, in time, these shifts in their thinking.
It's interesting with Student 4, they go back to previous versions, it's like… What happened? It's interesting, it's very clear, when you look at it that way, how students are progressing. Like 3 really made a lot of changes here, a lot of changing occurring and a lot of movement. I don't think this is negative, that student 4 goes back to earlier designs..
But I feel like Student 2 just got stuck at the beginning of the project, for a long time, and then they made some changes and came back, like a lot, They came back a lot by the end. This information is very useful to be able to see what the students are working through and thinking along the way. I think that's really helpful.

ME: If you were to rank the students based on this additional info, would you change it or keep it the same, and why?

I think I would still have 2 at the lower, it just doesn't seem like 2 is making a lot of forward progress. Maybe 2 is second guessing himself in the process, to be reverting back to initial ideas after making a lot of forward progress is interesting. I think I'd still keep 2 at the lower end of my ranking.
4 made a lot of revisions, obviously a lot of thinking for 4. I might change the ranking of 4, and making it higher than initially though. Because if I just look at the final product to me it

looks like, what I initially saw, without **seeing the fact that this student really was working a lot through the process; that would really add a lot of value to their project.** Because it might not be the best final product, but for that student, **to see their thinking, it would change my perspective of what I think that they accomplished with their time.** 1 seems pretty steady in their progress, but I feel like now 3 really stands out. If I had to… initially I thought 1 and 3 were about the same, but now I would have probably grade 3 higher. Not that I think it's negative that number 1 was synthesising information and staying with the same type of version longer, but I feel like number 3 was thriving in the process. Especially like in this part of the project, (where the failed attempts are), I feel like 3 really was thriving along the way.

Theme: the volume of changes = the volume of thinking.

ME: If you have these type of visualisations available, would you use them in the classroom and how?

I think I would use it because I think this shows a window into the thinking of students. About their process and design. I think it gives teachers more information than just the product the student is creating. It's more information to the teacher than just like transcripts of their experiences and what they're thinking, or what they're documenting. It provides with a continuum of their process, to really see their thinking along the way. Especially if you were to cross-analyse this with the things that students were self-reporting.
But I feel like, in my classroom, I have 27 students. So I wouldn't have them working individually, I would have them see students working collaboratively in groups. If I had this for 27 students that would be a lot to go through individually for every student, especially in addition to the rigorous content things I'm required to complete as well. So I feel like I'd rather than that as a group view to look at.

Theme: teachers identifying opportunities to complement this with students' self-reporting

Visualisation 3: blocks and connections

I think based on this, I would probably still continue to rank 2 and 4 lower, because I feel like and 4 are using the same circuits time and time again, instead of trying different ones. I would rather see something like 3, 1ish… 3 would be at the top of this due to the amount of connections they explore throughout this process. I feel like, looks like 4 kind of got in a rut, thinking, 'this is the way I've got to do it', whereas 2 played with it a little bit, but mostly did the thing. And I feel like 3 experimented a lot throughout the process.

Visualisation 4: kept versus discarded

It's interesting that all of your subjects were males. Because if I didn't know beforehand, I would have assumed student 2 is a female. Because research has consistently demonstrated that females would often write things and keep them away, as fast as they write them. So from initial plans you'd think that they did not create something of value because they will have discarded so many of their initial attempts to creating things.
I think this changed my perspective a little bit of number 2. Cause initially I thought that number 2 wasn't putting in as much effort into the project. But 2 made so many changes

that, so many different designs along the way, so there might be more value in student 2's project than I initially thought.

ME: Compared with the normal insights you get in an open-ended classroom, how do these visualisations complement what you see?

I think they provide a lot of useful information. Very helpful. It's another way of documenting the process along the way. My students, when they engage in their design process I gather a lot of data on my students' thinking. I do a lot with my students' self-reporting, and I have things where the students are showing the things along the way they are changing and showing their thinking, but I do not have a program that shows the changes and revisions. It makes it more accessible and easy to view and to look at. And I think it yields a more complex understanding of the process that the students work through and the challenges, if you use this in addition to what you already do in the classroom.

Resource:
https://www.amazon.co.uk/Coding-Playground-Programming-Computational-Childhood/dp/0367900963

Teacher D

Supporting STEM education in Philadelphia
BS in Mechanical Engineering from Rensselaer Polytechnic Institute
MS in Education from Pace University
Taught: grades 8-12 math, physics, and engineering for 11 years in NYC and Philadelphia, and ran a large FIRST robotics team in Philadelphia for 6 years
Completed a three-year NSF Research Experiences for Teachers (RET) program where he worked with 26 middle school math and science teachers from the School District of Philadelphia in the field of robotics
https://www.grasp.upenn.edu/people/daniel-ueda

What were the requirements of the project? Was there a description the teacher gave as 'there needs to be x number of developments', or … yeah, what were the requirements of the assignment?

ME: No
The way students interact with those materials is going to be partially, and even more than partially, affected by the way in which the activity was introduced to them. It seems like there was a lack of any structure. It was very much, like you said, open-ended. But you can have open-ended projects that have a lot of structure to them and a lot of requirements. This is extremely open-ended. So I would be careful about how you talk about the data that you're collecting about the students and the use of the materials, because I think it will be heavily affected by the way the activity was introduced, and has nothing to do with the materials that they were using. A portion of this analysis is just about.. loosely constraint problems and free, almost open-ended play. A large portion.. And you're going to have to tease apart what

part of the data is that, and what part of the data is interacting with SAM materials. And that's going to be had with one class.
The conclusions that you draw are tied to, not just the use of the SAM materials, but also to the way in which this activity is structured.

ME: When you work with open-ended projects, what was your criteria when you evaluate these type of projects?

First, it depends what content we're trying to get across. If we're trying to teach some coding, like using loops, or conditionals, or logic, interacting with the micro-controller, pulse modulation with a DC motor, circuits, inputs and outputs, if there is algebra or geometry involved… whatever content, and it can be any content, we're trying to get across, I want my first criteria to be based on my evaluation of whether the students are articulating, and not just articulating but demonstrating their understanding of that content, in this project. So whenever I create an open-ended project, I have to first consider how I'm .. well, first I'm going to consider what content I want them to understand, and then .. this part is understanding by design, like I'm going to figure out how I'm going to get them to demonstrate, or how I'm going to get them to demonstrate the understanding of that content. And then I start to create my project that gets me to those things. So that's number 1, the content I'm trying to get across.
But then, there is also content that is maybe less.., what typically people would consider content that are the things I've just mentioned, but also content about how to conduct an experiment, or how to troubleshoot, or how to work with a team, or how to communicate results, or those kind of.. Sometimes they're called soft skills but they're content, they are disciplinary content 'how designers work', or 'how an engineer works' or 'how mathematicians work'.
Both of these are learning objectives. The hard content or the soft content, those are my learning objectives. I'm going to start from there. That's where my criteria starts from and then I'm going to figure out how I'm going to get them to demonstrate it in a project.

Theme: 'soft-skills' are disciplinary content in their own right - their own learning objectives

So, I don't want to critique this activity, but .. I love large, open-ended ended long projects for students to do all kinds of creative things. But in that, I want to make sure I link it back to the content I want to teach in this project. Which is largely missing in this activity. Certainly there is content they are getting, they're learning how to use a servo, but .. that's how I would setup my criteria.
And to move on onto how I articulate that criteria, it could be in a lot of different ways. So I like to, if I'm going to do a project I like to set my criteria at the beginning and tell the students 'this thing that you create, whatever it is, needs to fit certain constraints. I often approach problems from an engineering perspective. So you have limited materials, or an ill defined problem, or a situation … here are the constraints that you have. Eg: it needs to knock someone over. It needs to know the piece over, the piece is 7cm tall, it needs to be able to knock them over - that's a constraint. And you need to demonstrate your success in such and such a way. You need to show that through experimentation that it does it repeatedly, so they have to collect data…
Every project that I do now, even at university, so like, I want students to collect data. I want them to have evidence that they've achieved this criteria. So I want them to collect data, they

can collect it in lots of different ways, but they have to show how they are going to collect it, kind of like a science lab design, right? And they're going to present that data in a certain way, like in a graph, or table, or whatever, and then they're going to present that data. Not only to achieve the criteria, but also make the clear case that they've achieved that criteria. That's the communication of the content, communicating like a designer or engineer.

Visualisation 1: final graphs
So I think, I would rank student 1 the highest. I don't know what the criteria is here, but it's supposed to detect whether someone is a particular location, student 1 uses a proximity sensor to give a value, and filters that value, down into whether they're at the location, or not at the location, and based on that activate the sound. That seems very good.
I don't see how any of the others do that.
Student 4 - are there actually 3 axes? He wanted 3 around the board.
How do any of the others implement a decision?
Ah, OK so with the filter, if it's not within the filter value, it does nothing. OK so in student 2 and 4 those lines are only executed if it's above the number if it's near in student 2, and near in student 4.
OK in that case.. I guess student 4 also does it pretty well. So I guess what student 2 has in addition to student 4 is a hold. So student 1, it's activating the servo, but to what position and for how long?
Ok I see I see… I guess it's a decision about game play. I don't know which is better. I guess initially I thought student 1 would be best, because they're creating cases, but student 2 and 4 are saying, 'in case it's not near, don't do anything', which is also fine.
I don't know what would be better, if it's the pressure, or proximity, for the game. I think either one would work, I'd having to know a bit more detail about how the blocks work and their sensitivity… it depends.
So then I don't see a difference between 2 and 4. I also don't know what would be better - the hold or the delay. So this brings back the point of that, I think it's why the design is so important. You want the students to articulate how they game is going to be played before they start making this circuit and the code. Because otherwise, no matter what code you create, it's like 'yeah, that's how it was supposed to be played'. So it seems like all of these work, but it depends on how they are articulated, in relation to how the game needs to be played, how it should work.
Personally, I like the coding in 1 the best, speaking from a computer science perspective I like the cases. 2 and 4 are roughly on par. But I don't get how student 3 works, because they don't manipulate the pressure at all. So I'd put student 3 last. 1,2, 4 seem like they all work. And I can't tell which one would be better.

Theme: it depends on the game's objectives, on how the students designed the game to be played - first very explicit link to the final graph's success being entirely linked to the objectives of the game as the students envisaged them

You mentioned the teacher wanted to get students to go through re-designs, or iterations, which is great. Iterative design is a great thing to do. But if they have nothing to compare to what they wanted to happen…. So they had an idea of what they wanted to happen, they make this, then they take data about how it actually works, and take back and compare it to their original requirements, what did they want to happen, and they see a difference, now they are going to redesign. First they think, OK, how are we going to change the code before they go back and tinker with it, cause again, one thing I didn't want students to do if I'm doing robotics, I don't want students to just do trial and error. I want them to make a plan. OK, here's how we're going to change the code, we're going to write that down, and then we're going to change it. I don't what them to just do trial-and-error. Trial-and-error doesn't teach anyone anything. Unless they had something that they wanted to achieve at the beginning and have that to compare to, then what would they redesign it? It works.

ME: that's actually not true… and now what happens.. Emphasise the optimisation of both goals and trial-and-error.. Both get redesigned based on evidence!! And goals can emerge from trial-and-error too!! Make this clear in my thesis

Visualisation 2: approaches over time
That's really cool! I like that part a lot! I like this a lot, I'm not sure what feedback you're looking for but what I'm going to say is, that both from a teacher perspective and a research perspective it would be a wonderful… It would be wonderful to see these steps and have students write a couple of sentences on why they made this change. Why do they go from this to this, and then this to this. You're <you as in.. someone in general> going to try to guess what they did, but you know, having their thinking there, again both from a research perspective and a teacher perspective, is fantastic.

Theme: Dan clearly links again to using these with the students, evoking their goals and their intentions and thinking process.

Oh yeah, absolutely, I would use these with students.

Oh wow, student 3 went from very complicated to very simple. Yeah, I think it's very interesting to see this progression, absolutely.

ME: So if you were to comment more on the students based on this additional information, and rank them.

OK, looking at this one, as an example.. <student 2> again, without students' writing, without their explanation.. So one thing I see with this student for example is that they are going from the proximity sensor, to the pressure plate, back to proximity, back to pressure plate, to a slider, and finally stick to the pressure plate. And I'm seeing that in all the ones I've look at so far. So I'm seeing a lot of trial-and-error, a lot of 'try this, see if it does what I want it to do, and then try this, oh it doesn't do what I want to do, I'll try this thing, oh it still doesn't do what I want it to do, let me go try this other thing, oh now it does it what i want it to do…'
So my point is, this is why I don't like… i want to teach kids to move beyond trial and error. It's like the whole point of maths or physics is to eliminate trial and error, or for any science for that matter. I don't see in here much rhyme or reason for .. again, I'm going on nothing but what they've tried. But if they are going back and forth between the same device, then why are they making that decision to go back and forth? If they were collecting some kind of data or they were writing about what's working and what's not, then they should just switch once. They should try the proximity sensor, and say 'this isn't working, i'm going to try this', and either it works better or it doesn't. So stick with that or go to the original. So yeah you can go back once, but you shouldn't go back and forth, and back and forth. That means that you're just randomly trying things.

So this one (student 2) is pretty short, they don't do a lot of different things. They try out a few different blocks, I get that part, but also you got the wait, they stick with that for a long time, then they do the filter and the wait, then back to the wait, and back to the filter, with no wait also, now there's pause. So.. i don't know, if feels like there's a lot of trial-and-error, putting blocks in and trying out different things until they work. Which worries me, both from a teaching perspective and what I want students to learn and also a coding perspective and how you want students to learn how to code. You don't want students to just try different things until something works, what do they learn from that? It seems like they don't know what … it seems like to them that success is not about.. The proximity sensor is better than the pressure pad for this reason, or vice-versa. It seems like what they are doing it is saying 'this combination of things works better than all the other combination of things that I've tried before'. And that's not a good place to be either. If they are going to try out components and try them out and see which one works best then they should, try out the pressure sensor and decide, OK, is the filter better or the proximity, or a hold button, a wait button… you know what I'm saying? . And then use the filter and decide.. Is a wait button better, or a hold button better…

Theme: but trial-and-error is an essential part of LEARNING… and it's an essential part of what leads to maths / physics / scientific truths… yes the end result is to eliminate trial and error, but ironically, you can't do that without engaging in trial-and-error in the first place.
Theme: yes.. But it's NOT random. Because the input goes back and forth, but the rest of the circuit changes. And the students don't trial-and-error randomly. They might be more or less systematic about their trial-and-error, but it's never random either.
Yes, they do put things in and out and trying things out till they work.. But that's kinda crucial too.
Basic trial-and-error informs their goals, and they learn to try things out in increasingly strategic ways, to first, define increasingly feasible goals, and second, to get to those goals quicker. But the more random trial-and-error is an initial essential part of that, is that leads up to that more strategic way of problem-solving.

So I'm seeing trial-and-error. This shows why you want to give the students the tools to test, make decisions based on data, and then move on to the best design and give their rationale as they move through the steps.

Me: WOW. I think the kids are getting A LOT from this...spill out what they are getting from it.

ME: If you had this available in your own classroom, how might you use it?

So I've never seen this kind of approach in any kind of comparable tool. Whether it's LEGO Minstorms or Arduino controller, and I think it's fantastic. So how I would use it is..., if there was a tool in SAM, where this kind of feedback was given to them automatically, so you have this kind of visualiser that shows their last design. Now you've got this design, and the same visualiser, and underneath, as a teacher, I would give them, I would make them give an explanation. Like you comment code to say, to explain to other people and to yourself, why you're doing this thing. **Good programmers will save their multiple instances as they are going, and say, this is why i did this thing before, and now i'm doing this thing for this reason. I want that history so I can see what the evolution of this is**. This allows you to do the evolution of not just your code, it's also your circuit.

So I would put in here the ability for students to comment on the reason why they did this and the reason why they've changed it, and some data in there about how this performs. And you can look to see how the other thing performed, and you can compare them and make decisions as they are going based on that data. I think that would be great, it's a super cool tool.

In the end, if you hand this in to the teacher, the teacher then has a history of design iteration based on data, and that's wonderful. You can use this as your entire criteria for evaluation of how the students built their circuits. Did you make design decisions based on evidence?

Visualisation 2: blocks and connections
So, what's interesting is .. with student 3 for example it's a LOT more connections than 1,2,4. You have a lot less lines for 1 & 2 than 3 & 4, and that is reflected in the number of design iterations they have. And then I didn't look through the design of 4 in contrast with 3, but I'm guessing that student 3 used a lot of blocks. Whereas student 4 went back and forth with designs but didn't use as many blocks.

ME: exactly!!

So it seems like this is another way of seeing the efficiency of their design process. Whereas maybe student 2 had the most efficient design process, maybe? A thick line for one circuit, less outputs, so I'd have to dig into it a bit more, but maybe this is a way to demonstrate the efficiency of their design process. Before you can say the amount of trial-and-error in the process, i could see i before, and you can see it in this one. This is maybe a more mathematical, quantitative way of showing it.

ME: What about exposure? Arguably someone could say student 3 gets exposed to a lot more functionality than student 2 let's say.

It's tricky. Again it goes back to what you're trying to teach. Cause if you're trying to teach good coding, good design, then you do want to have efficiency. The faster you can get to a best solution is definitely the best path. But if you're trying to teach how to use a lot of blocks, and have kids test out a lot of blocks, then yes, I guess, student 3 has learnt a lot about a lot of blocks. But then… yeah.
I think that's true, I think you want to get to a point if you're teaching kids how to code where students think about a problem, mind map it or sketch it out on paper, write pseudocode on paper or whatever, and then they can get to the point where they write the code and get it right the first time. You really want to get to that point. You don't want to get to the point of student 3.
Obviously you don't start there, but you want to give students the necessary tools to get there. I really do think that student 3 is an example, and student 4 also, in looking at their iterations, how many their were and how many blocks they chose it's almost as if 'if you put enough money enough tools and put them in a room, they'll end up with a rocket'. It's almost like student 3 closed their eyes and kept trying things over and over again… what are they learning from that? They're not learning about the blocks… I don't think…

ME: I totally disagree with this…show the story in the thesis

In my mind, this visualisation would be hard to use with students. But this, it would take a lot of data analysis background for students to look at this and understand what's going on.
I think this allows you, as a researcher or teacher, you can create a mathematical model of this, and articulate how efficiently students arrived at a solution, and how many times they went back and forth with the same block. So you can really quantify the efficiency. So I think it's more valuable as a researcher. I'm not even sure how a teacher would use this.

Visualisation 3: kept versus discarded
Overall, I don't see this as being as valuable as the other two. I think it does show, for example, that 1 and 2 had a more efficient path to the solution. 3 and 4 is all over the place.
But i don't think it does as good a job as they first two. And I think that a good programme or a good project or a good design is sometimes going to add more.. Cause you do want to end up as simple as you can..
None of these have what i feel would be the ideal, which i guess would be start low, go higher, and then come down a little bit more. That would be the ideal situation, and it would need the ideal project to do that, and i don't know that this project was that.
I can't really pull much of this visualisation.

ME: Compared to the type of insights you get normally in open-ended projects, how do these type of visualisations complement what you normally observe in the classroom?

When you're in a classroom and working with students you often don't see those iterations that they go through. And I think you gain a tremendous amount from knowing the history of changes. Absolutely. You can start to understand their thinking process. I think it's aided a lot by having them explain those decision, like in the first visualisations if they were able to put text to those changes, and I've certainly done that where I have students explain and I have students write out when they're going through changes and why, but typically in coding challenges, or circuit challenges, you don't do that, considering that they happen so rapidly. So I think it's extremely valuable to have that history of changes.
For a teacher to get that, cause you understand what students are thinking as they're going through, and I think it affects what you do in the future, it affects what you do on a day to day basis, it effects how you're going to … if you see them going back and forth between these two sensors for example, then that means they don't really understand how to test out a sensor. So maybe I'm going to introduce a lesson where we're going to collect some evidence about which sensor works better for their application for example.

Theme: using the visualisations to inform the activity design

Teacher E

Our school test scores are really high, but we were looking at what we can do to go beyond and push the students further. So we looked at things around innovation mindset, we turned to the 'Innovate insider in box' book, and we thought about how can we integrate technology into our curriculum and how can we do it seamlessly.

With a group from Florida we setup an Innovation lab, which is a glorified MakerSpace, but also both low level and high level tech available in that lab. With the innovation lab we created environments for students to be able to design, create and build, explore, go through that design model in real life, take things into that higher level beyond exams.
As we did that we put simple things in the lab that had some higher tech. We used the SAM Labs, MakeyMakey, LittleBits, 3D printing, VR goggles, iPads and computers for kids to be able to look at 3D images they were creating, LabDisks so they can actually test wind, temperature, things like that. So when they are prototyping they can test and do those kind of things. But then we also had very low tech. The room was designed into areas the kids can go into. There was no dedicated teacher for that room, but you could find out the times when it was available and be there, explore or create things. Especially after units or discussions they had.
We contacted SAM Labs who did some webinars but also our kids did some webinars, that they were able to participate with the SAM Labs people to be able to use the kits. So once we were able to established some kids that were well versed in SAM Labs, then we had them be mentors for students in other classes. So we had 5 of the STEAM kids, a classroom kit and charging board.

ME: Do you evaluate at all what happens in the Innovation Hub, or is it mostly left to the childrens' freedom and imagination?

A little bit of both. If it's a design challenge where they are supposed to used that, then we'll have a level of evaluation in their presentation with a rubric of some sort that counts towards their grade that's multi-disciplinary. Other times it's not, and it's really simply for them to be able to explore.

ME: What is important to you when students engage with SAM? What is important to you that students do?

The collaboration. The dialogue that emerges and the collaboration to get to the end product. So I'm looking at the questions they ask each other, we also try to ask questions that don't guide the actually answer but guides them to think a different way. That dialogue and questioning happening between all the members there in that room.

ME: Do you document any of those interactions, and if so how?

Sometimes we video, to look back at how they talk to each other, to be able to go back and talk about it in front of a class and show the process that kids are doing exactly, and the process when they are not doing it at all, so working in isolation. And how the products they're trying to come out with just one idea, and how products turn out from multiple ideas collaborating. And how rich the dialogue is. That modelling of it is good and also teaching the kids to question is good.

After the context video:
I have some observations. What is her objective for kids to walk away with? What is the target learning in this, besides the integration of some history content?
Do the children now, do they already understand the content and now they're able to use to content in a game form to check their understanding?

Let's make sure if this isn't just for fun.

I would give them: I want a buzzer, a sound, a spinner and an element of surprise. And it needs to fit on a pizza box. So you give them those parameters and say .. go. Rather than giving them such specific ideas.

Visualisation 1: end graphs

Student 1 obviously…
Number 4 is very limited, just one circuit. The same as student 2. So I would say 2 and 4 are pretty limited. Student 1 looks to me like.. They understand variables, that's definitely going to be the highest, ranked 1… student 3 also has a bigger understanding. 1 and 3 have a better understanding of some other key components they can add to the structure of the game.
Student 1 doesn't need anybody. And student 3. But student 2 and 4 need some other people to talk it over with and validate some ideas and give them time to explore it. If you're aiming to complete the game faster, student 4 is fine. There's positives and negatives for all of them. But I would question why is student 4's more efficient than student 1, but why is student 1 able to create things that involve 'if you do this, then you get this' (conditional).

Visualisation 2: approaches over time

This is their trial-and-error and how they did it, and how they came up with this. That's cool.
Student 4 is all over the place. To come up with that, and then to come back here.. Their growth was minimal. They're at a slider right now. They have no concept of… they're all over the place. They start out…
Student 1, which I thought was kind of interesting, was … this is where he starts really learning about the variables. And his growth is there. And then his action at the end is not much more. He got it and he was done early. Number 1 is bored.

Student 2 is limited… They just added a pause there.
3 is working it. He's really trying to … this is cool how you aggregated this. This is impressive. You can really see the kids.. 3 is.. They're right there already, they're
Student 4, I told you, this one doesn't know what they are doing. This one, is like 'this works, ok, let me do it, i'm done'. I mean, they are so simple.. They though about it a littl bit different, they're trying… but this one doesn't even work. <talking about a version which is actually valid..:>
I mean… yeah, I don't know, that's just my thought process.

When you go back and look at the final graph right now, I think it's good for a teacher to look at what they were doing. Student 1 didn't have enough challenge, and got bored. If you looked at that graph back in November, you had 14 days that you could have challenged that kid.
4 is either lazy or has no concept of what to do, so how much interaction did you have with that person? So the knowledge that you gain from this process is awesome, because if you, as a teacher, it's like a reading level. If you read with them every day, or if you look at the data daily, then you know what's the next thing to do. As a teacher, if you didn't know what

student 1 was doing, you could talk to them and have them be the teacher in the class… it definitely adds some more depth to the blocks.

Positively, you can see that kids are utilising the opportunities to test their strategies, so they're obviously engaged. But you can also check the level of engagement, so my question is, 'if you had a diary / blog/ way they could give feedback with a question every day that was mapped with this data, then you would have way more information'. This is just one little bit of information of what SAM blocks they used that day and what they interacted with, whereas maybe they stayed still and it was only those blocks because they were trying different variables. You just don't know if you don't ask questions. **So the questions that you ask during that process, as a teacher, is where you do your work**. The visuals would definitely prompt me to ask more specific questions.

I don't necessarily know that I would change the ranking, in looking at graph number 2, I got more information about it. The effort could be the same.

In our schools we do a lot about effort. If a kid turns in a paper where they score the same amount. But one student's effort to get a 90% is 10%, but the effort of another kid was at 100% to get 90%, they both got the same grade, that's great. But the effort they go through dictates the amount of support they need to get that grade. The first child is no challenged enough. To me, that kid, I'm just as nervous about, because they look great on paper. But in the classroom, they're not challenged or questioned enough, to dive deeper into what they have to be able to give. If we don't look at effort, or efficiency, or the way that one kid's learning, more than the other then we're doing a disservice to our children.

Visualisation 3: blocks and connections

Student 1 is efficient. Student 3 is all about figuring out .. they're creative, very creative. They are thinking outside the box, they are wanting to test, they are finding things that don't work, and when they get to the system they they like best, they are sticking with it and testing it multiple times.
Student 2 is kind of.. They found the right way, and kept doing it. They tested a little bit, but once they found what they wanted, they stuck with it, and that's what they did. And you can tell in their final project.
Student 4, again, 4 has issues. Student 4 is trying to do what 1,2,3 are doing, but only knows how to do it one way. And it's so low level. And they try, and they found.. When you go to red, yellow, yellow, yellow, or red, yellow, yellow, blue, they probably got excited and tried it a couple of times, but it was too hard to do it that way, and went back to their other way. 4 needs support.

Theme: some teachers read waaaayy too much into it..draw way too many conclusions.

Visualisation 4: kept versus discarded
I don't like it as much. Because I just think that, personally, I don't feel like … number 2 is just like .. doesn't know what they are doing. Number 4 found the connection and stayed with it the whole time. And 1 and 3 basically they just kept trying things in different ways and once they got to a connection they liked they stuck with it. But they .. I just think that .. I could tell in graph number 2 (approaches over time) better information than this one because I could

see what connections and blocks they were using, whereas in this one it's much more random and … i don't think i'd use this graph. It's not telling me any more. The other one has much more value. I don't care that student 3 discarded at all. Student 4.. I don't know. It's information, but i don't know which blocks they used and which ones they didn't from this one. What made you do this one?

I like you other graphs much better. This graph doesn't even really.. It just highlights student 4 even more like 'I don't know what I'm doing'. I get that information better from the other ones. I think you could show the picture, if you just show one student, and you can talk about how kids need time to be able to practice, or try. And you don't see that, and then look at the results you get. So in using that, I like the description of the iceberg, we talk a lot about that in teaching - if student 1 would have been given a more difficult project, his could have looked like student 2. I like the thought of where you were going with this, but these could look so different, so I wouldn't use it. But you could use one of these graphs, to make your point.

ME: compared to what you observe during your SAM projects, do these visualisations add or complement what you real-life observations?

Yes and no. Yes if you are using the data to guide the instruction.

ME: In what way would you use these in your classroom?
I would say that identify the kids that need challenge, scaffolding. This is the minimal amount they are doing, but I need to put them on a pathway that's more challenging.
Some of our kids that are not the smartest on paper, are the best at being able to talk about things. That can be built in.
If you're truly wanting to impact the learning, I don't know that I would use this in every lesson, but I would certainly say that, a baseline lesson, a middle of the road lesson, and a final, 'how are we working' lesson is definitely a time when, as a teacher, I would want that data so that I would be able to speak to it.
I would definitely use it to target the type of questions and discussions you have with the kids. And I would do what you did, you didn't tell me the answers, you didn't tell me who these children were. So in the class, I'm not judging.. If you're looking at the data, you might be student 4 a lot of times, and that's OK. And we're going to get you to look like student 1. And Student 1 can look just like student 4 if they are being challenged.
That's.. That's the ability to have time to teach kids how to analyse data and have them a part of the conversation so that they feel comfortable enough to be able to share their experience, and be able to talk about struggle. In a non-threatening way.

Theme: all teachers identify the opportunities to ask students better questions - and they identify that as a pedagogical technique - so data doesn't have to always give answers!! Giving questions is just as valuable!!

Theme: teachers identify the visualisations as 'showcase' examples, as things to use to bring awareness to the experimentation, to exemplify what it looks like, rather than necessarily tracking them constantly to identify interventions

Theme: teachers are seeing the value in using them to change their project design, adapt based on what the data shows.

I learnt a lot too! Just to confirm my own thinking and being able to have someone else dialogue with me about their thinking. You can only get better if you seek to learn more, so I also enjoyed it.

Theme: metacognition again

Resources:
https://www.amazon.co.uk/Innovate-Inside-Box-Empowering-Innovators-ebook/dp/B07WG9P1DX

Teacher F

ME: What is your criteria for evaluating open-ended projects, and how do you materialise it practically?

I think the most relevant course for me to talk about is my robotics class, we use Arduinos. I also teach a mobile application programming class where we use the MIT app inventor, and I also teach a class on simulations and game design using NET Logo, and I also teach a class on web design which is straight html, css, javascript and php and sql, that's more of a coding class, not block based. I think that's all I teach. Oh and the IB computer science that's in Java. But just to talk about robotics, I have the students keep an engineering notebook. The notebook is a documentation throughout the term, on a weekly basis of 3 primary things. So each notebook entry needs to have: what they accomplished that week, what they didn't accomplish that week, and what they hope to accomplish next week. What they accomplished and why, what they didn't and why, and what they hope to accomplish next week and why. And I have goals for them throughout the term, so we use the projects that are in the Arduino projects book, an open-source book that's out there. And what I expect from them, how I grade them is the completion of the notebook. I expect that to have video, pictures, coding examples..I encourage them to work together. They have their own engineering notebooks, but I want them to often be doing partner programming or partner projects, and they can change partners project to project. They can work with whomever they want. Really it's the completion of their notebooks is more important than the completion of their projects. A lot of their engineering notebooks include things that say 'I didn't accomplish what Mr Schildge set out for me to accomplish this week because I didn't have enough time in class, and I learnt this but I was really confused and I didn't understand this other thing.' and they don't loose any points for saying that. I also have quizzes throughout the project but the notebooks are weighted more heavily than the quizzes are. So there is an incentive for them to try and understand the material prior to the quizzes, but I'd rather them be honest about what they know and what they don't know, at least to themselves. And I accept late work too, if they don't complete their work in time and take longer, I don't penalise them for getting things in before the end of the term. For some students that slack is not always a good thing, because they'll be tempted to take advantage of it. But with regular reminders, they tend to do pretty well.

Theme: all teachers distinguish between learning and end results
Theme: all teachers feel they can observe the students 'thinking process' from the visualisations
Theme: all teachers appreciate the history and think of it as valuable to see as it is
Theme: all teachers have their own ways of delving into the 'process' and getting students to document their 'process'.

They can also see each others' notebooks. Sometimes I'll take time out of class for me to show off a particular entry from one of them, and that motivates them to work harder. One of the greatest challenges, particularly with distance learning is motivation. How we can keep students excited and interested with what we're doing in the class. Some students are going to be motivated by grades, some students are motivated by the learning, other students are just motivated by just the recognition and approval of their teacher. So sharing students' work with other students can give the students you're highlighting the work of that sense of 'wow, i'm really doing a good job, I'm going to keep this up'.

ME: What's important to you for students to do when they engage in these kinds of questions. Where do you see your biggest challenges practically in the classroom, do you feel you have all the information you need and where are the biggest gaps in these open-ended robotics contexts?

I feel my biggest challenge as a teacher in the classroom is to effectively challenge students at all the different levels that they come in at. I create Hacker assignments sometimes, which I present as going beyond what the main assignment is about. I got this from the CS 50 course at Harvard. They have these Hacker challenges that go beyond the initial scope of the assignment. So I say 'here's a hacker challenge for you guys, to take advantage of this opportunity to learn recursion for example, which is not in the scope of the entry level course'. But you can do the same here, but see if you can do it without a loop.

I also try to emphasize at the beginning of the year, I want everyone to remember one word, and that word is 'enough'. You're enough, you have enough to be successful. There's no magic quality, no secret sauce, no intrinsic quality that anyone comes into this classroom with that's going to guarantee them success. It's all a matter of effort and persistence. You can get this.
A lot of kids come into my class, especially the IB, with the mindset of 'this is a requirement for my graduation, i have to take it and I'll be lucky if I pass'. That's wrong, you're going to succeed, you're going to love this material cause you're going to work really hard at it and you're going to come out the other side of it with your mind blown. You're going to come out of this course so excited you're going to want to take more. And even if you don't, hopefully you're going to come out of this course feeling successful, because you have enough in you to do it. So I try to re-iterate that message.

Visualisation 1: end graphs

I am drawn to solution 1, because they are using a conditional statement. They are returning a value from a function, in terms of scaffolding to do higher level work this is some of the foundational stuff I would expect them to understand. Contrasting that with student 4, whilst they used 3 servos, and 3 proximity sensors, it seems like what they've done is repeat the same thing 3 times. It has no greater value than student 2. Student 3's work, I like that they have a timer to delay the sound, so they're thinking about the user's experience and how to create a certain effect, and how to create that effect by putting that timer in there.
So I would say student 1,3,4,2 in this order.

Visualisation 2: approaches over time

So this shows you what their blocks looked like as they went along. OK.
Ok. student 1, who I initially ranked the highest, seems to have done the least amount of changes. Student 2 seems to have spent a good amount of time with the same concept, and then try to tinker, found that didn't work, went back to their original plan, and then tried

something new, add it to that, went with a different input device completely, went back to something that hey'd done earlier, and went with a pressure sensor at the end.
Student 3 went with a whole bunch of different things. Tried a whole bunch of things that didn't work, and eventually got to the final solution that they landed on here.
And Student 4 tried a variety of things. I'm curious when they introduced the 3 axes… right at the end.
This is really nice in the sense that here you can see how much work the student has actually put in to their project. We struggle with that as a school a bit. We talked about introducing effort grades or something like that, alongside the grade that they receive, and the discussion always comes back to 'well, are we grading students on the degree of complication of the material at the end of the term, or are we factoring in to some egress the amount of effort already and rewarding them for that?' and my intrinsic response is, and looking at this especially, is that 'I want to reward the students that puts in a lot of time and effort into something. Because in the long run in life, we do reward students' work, we reward people who work hard.' We see people who are putting in a lot of effort and we want those people on our team, even if they don't always come up with the right solution because they often contribute things in other ways. That's one of the reasons why I take late work, it's one of the reasons why I reward them more for their completion of engineering notebooks more heavily than other quizzes because, I remember being a student, sit down in front of a quiz that you know accounted for 60% of your grade, and you learn something in the quiz but it's too late at that point, and you don't have the opportunity to take it to the teacher and apply it in the class.
We still don't have an effort grade. But what we're doing in the lower grades is moving towards standard-based grading. Standard-based grading allows for much more of a specific standard that gets written on their report card that they have not met, that they are approaching, or that they have met. When you standard-based grading, you have 'meets expectations', or you have 'exceeds expectations'. And you tend not to have an 'exceeds expectation' grading, because what we want our students is to 'meet our expectations'. We don't want they to feel like they have to strive for going beyond the expectation. That's creating undue stress on their students, their parents are going to simply say, 'you're not doing well enough by meeting expectations'. Everyone has to be above average? That's impossible.

Theme: Teachers often refer to these practical design interventions that they implement in order to encourage process, iterations, effort - these need to be concretely acknowledged and made visible, and practically designed for and intentionally taken into account and rewarded: documentation, late work, effort points, debugging each others' code, etc.

Theme: the effort is the basic foundation. The trial-and-error is the basic foundation. It's not everything, and the effort and trial-and-error needs to be effective and improved, but it is the foundation of any learning. So we shouldn't discard it in our search for additional dimensions. It might not be enough on its own, but we cannot exclude it, because it's at the base of any other dimensions of correctness, efficacy, 'productive failure', etc. So use data to go more into detail, not the opposite way around!!

I think of my own children, and if they are working really hard, but they are not hitting the ball in the park every time, I don't want them to like their effort is not being recognised.

Theme: especially in open-ended projects, where simple end-products might be the best / most worked-on, or where even failed products can have a lot of learning behind them, the process is everything.

Well, I mean, my initial gut would look at the degree of complexities and iterations they've gone through.
ME: So still complexity, but with a different definition this time!!!
Student 3 and 4 seem to be… the students have tinkers a lot more than 1 and 2. Students 3 and 4 have put in a lot more time, have learnt a lot more about what works and doesn't work than students 1 and 2. One of the things we do a lot of in my class is debugging each others' work. Because I want them to look at what others are doing and be forced to follow someone else's logic. So if you were to ask student 1 to debug student 3 or 4's work, they might really struggled, because they won't have even looked at, they might not have seem this type of arrangement of the blocks, so they might struggle. But give student 3 student 1's work, they might say ' well, I did that back in Dec, and I chose not to go down that path because of x,y reasons'. So yeah, to rank them, I would say, 3 - I had ranked student 3 before student 4 before, so partially because of that I'm going to keep student 3 higher than student 4. I also like that student 3 finally laid on a solution that does involve two outputs at the end here, a player and a servo. And then student 4, and then I would put student 2 and then 1.

ME: Between 3 and 4, student 3 goes through a lot more invalid versions. Does that matter to you?

I think that's awesome. I think it's great that they found incorrect solutions and persisted. I would worry that, if they were here (the 5th bar, which is also the 3rd unique approach), and this lasted much longer. I can see here, they seem not to understand what the code block was doing. And they seem to have figured it out, because they seemed to have figured it out (the next versions are valid). But they laid on a solution that didn't include the code block. So, I think, what that tells me is that they realised they could use this particular tool, but they chose not to because it wasn't necessary to accomplish what they were trying to.

ME: Would you use this kind of info in your classroom, and if so how?

I have! I have an online text book for my IB computer science classroom, as they track student engagement. So I will often send a message to students who I see not spending a lot of time on the coursework, and I say 'hey, I noticed that you haven't been spending a lot of time working on as I'd expected you too'. I can correlate that to performance on tests and quizzes and say 'hey, you did poorly on this test, and i see you didn't spend a lot of time'. But you know what, that is almost never the situation. But I often find that it's the students who spend a disproportionately large amounts of time on the material, on the textbook and then do poorly on the tests. So that is really helpful for me because I sometimes will assume, if the student did poorly, that they haven't been working hard enough. And I think that it's really dangerous and demotivating for students, for their teacher to say 'you did poorly, that just shows me that you haven't been working hard enough'. What that tells them is that my teacher doesn't recognise my effort. This thing called the academic mindset, I'm just going to pull it up, the academic mindset is four different things here: beliefs that students need to come into a class holding in order to achieve success. And they are 'I belong in this learning community', 'I can change my abilities through effort' - that 'enough', of you work hard, you will succeed, ‘I can succeed’, and ‘This work has value and purpose for me’. I polled my students and generally it’s the last one that tends to be the hardest for students to see or to say that ‘I strongly agree with this statement’. But if your teachers are coming back and saying, after a quiz, ‘hey, you just clearly didn’t work hard enough’, the teacher is clearly undermining number 2 ‘I can change my abilities through effort’ there. And so being able to know what a students’ effort really is, at least in terms of the time spent on it, the textbook, or in terms of using the platform, it allows the teacher to say ‘hey, I see that you worked really hard at this, but I can also see that something is not clicking. First of all, it’s not you, it’s not your problem, this is our problem, and I want to make sure we’re able to figure out how to help this, how to make this click’. That is a lot more ultimately successful in the classroom.

The academic mindset came out of reading a book called ‘How to help children succeed’ by Paul Tough, and he cites this in his book. And he works with Angela Duckworth, you know the Grit stuff.

Theme: link between end results and effort.

Visualisation 3: blocks and connections

Student 1 seems to have less complexity, less experimentation than Student 3.
Student 4 seems to really have relied heavily to the Keyboard connected to the DC motor or whatever this output is here. Student 2 have kind of included some other components here, but maybe just dragging them in there and depleted them straight away. Because it seems like they’ve really relied heavily on the pressure the toggle, this path. Obviously in contrast to student 3.. There’s that expression of ‘if you put enough monkeys in a room with enough typewriters they’ll eventually pound out the words of Shakespeare’, student 3 seems to have taken that approach. If I use enough of those blocks, something will work. Student 3 I might be concerned, might not really understand why the blocks worked, the components that they put together, because it does seem like a process of trial-end-error. Which is fine, as long as they are understanding things are the way they are and why.

Theme: all teachers see trial-and-error. Some think the amount they are seeing is positive, some think i’s negative. But they again converge in concluding that it depends on whether the students are understanding what they are trying and why - so actually, it doesn’t matter whether the teachers see them as positive from these particular visualisations, because they would all verify this with the student, and make their decision that way.

ME: Do you find such a view useful? And if what way would you use it if it was available?

I imagine most of my students would fall into a situation where I wouldn’t really need to look at this. But where I would look at this is for a student who is struggling. Doing poorly in a test or not got their work completed in time, and for them I would dig in, with as much data as I can, what they’ve been doing. And then I’d look at this and say, for instance, if they are in student 3’s category, I can say ‘I see you’ve spent a lot of time on a lot of different things, but I can see that you you haven’t appreciated exactly what are inputs, and what are outputs. What does a sensor do, and what does a filter do? Let’s back up a little bit.
This makes me think back of the concept of scaffolding, and how that applies to project-based learning. In the traditional classroom, we talk a lot about scaffolding and being

able to help students develop more complex projects. The temptation with open-ended projects is to throw that scaffolding out the window and just tell students, 'here are the concepts and tools we're working with here, go crazy.' but scaffolding still plays a role in that, you still have to provide a certain structure, especially for those students who are completely new to the field of computer science or robotics. Otherwise they don't know where to begin and it can actually be quite scary seeing their peers able to do things relatively quickly and them thinking 'oh my gosh, I'm being left behind'. That's kind of an aside.

Theme: Look at what exactly they've been doing as a way to support!!! Have views that show what students have been doing, and just that, is valuable.

Visualisation 4: kept versus discarded

That's really interesting. Something about student 2 is so revealing here. Not sure what exactly.. What is going on here, but it seems like they were tinkering tinkering tinkering tinker, and then they were like 'oh I got to submit the project', and then handed it in.
I think that student 1,3 and 4 seem to be … the more segmented the graph is, the more changes it seems to show on their project. The more segmentation there is, there more it shows that they spent time making changes on the project. I would say, obviously I like more changes, more experimentation. The more highlighted blocks, deep orange or deep blue which means they've tried components that they haven't tried before.

Theme: more experimentation, more trial-and-error, more changes is good!

ME: How do these visuals complement what you observe normally in your classroom?

I think they're great. I use TinkerCad in my projects, and I think it's great, because it really allows students to tinker with their projects, and not destroy the arduino board in the process. But I'd love it if they had these kind of visualisations as part of tinkercad, if they had some kind of tinkercad classroom account where I would be able to see my students' progress, cause they're making changes.
But these kind of visualisations are very helpful for teachers. Also you can sit down with students and show the students 'hey this is on my end, how I understand your effort. And what this is telling me that you haven't really been trying that many different things'. It creates really good opportunities for discussions with students.

ME: What I'm looking for is red flags. When there is a problem that I need to jump on. I want to know, very clearly as a teacher, when the student hasn't handed in an assignment, when there is a pattern of behaviour that's beginning to emerge that I should be aware of…
Eg: most of the students have sent x amount if time on the platform, but student y hasn't. I really want that right in my face because I've got a lot of limited amount of time and limited energy to spend on students' multiple different graphs.. It's really good information but if there's a way of automating something, at least in terms of drawing my attention to something, that would be really helpful.

Theme: Not sure visualisations 2,3,4,5 hold much value for the classroom context. They do hold value for the discussion with teacher, awareness of how the trial-and-error *experimentation process unfolds, but the one visualisation which can practically be used as a classroom intervention is visualisation 1.*

Theme: what the visualisations don't do! - they don't provide red flags, of thresholds of what is 'good' or 'bad' or 'productive' or 'alarm bell'.

Resources:
https://blog.mindsetworks.com/images/hierarchy-of-learner-needs-v03-banner.jpg
https://www.mindsetworks.com/go/academic-mindsets/
https://paultough.com/helping/

Teacher G

Visualisation 1: final graphs

So at first glance, I look at how many parts, or how many pathways do they have in their final graph? So first impression you always want to look at the abundance, so then you narrow down to 'are those abundance just a repetition of things, or are those just something else'? So in my opinion, student 1 is probably the best work. I think theirs is the best because they have 2 different pathways of logic. Student 4, initially, when you look at it it's like 'wow, that's like really a lot of code, but it's the same thing copied over and over again. And student 2 is kinda your typical student. I think that's kind of the average student, your typical student. So I would say 1, and then 3, then 4 then 2, would be my ranking.

Visualisation 2: approaches

Ok so student two goes back here. So they went backwards because they were trying to figure out what it was they did, incrementally to try and improve on that.
So typically, this is what I think, the amount of attempts, looking at Student 3, is not necessarily a bad indicator, they just came up with a lot of ideas. That might not be necessarily bad or anything. But I definitely student on the higher end have fewer attempts.
So look at the time for student 1, it's gradually consistent as they are progressing with the harder schematic. Time is increasing.
As you can see from the third student right here (student 3), the reason why they're having a high number of attempts if because they're trying a bunch of ideas that didn't work out. So this area here (where they try a lot of invalid things), it's actually pretty typical of engineering ideas. Sometimes you just got to try it out. Cause it's all about open-endedness and it's ok to make mistakes. But that's the reason why they're having so many attempts, because look at their timing here, each is very very short (the frequency between attempts).
Preferably, in my opinion, I prefer students to be like student 3. Because looking at this graph right here, let's bust out some ideas and let's try it. Instead of being stagnant on one idea, and just kinda of be like 'oh, I don't know what to do…', let's just try a bunch of things, and it doesn't matter if they don't work. So I really like this curve here, a lot of attempts, a lot

of ideas, different ideas and different schematics but it didn't work out. Eventually they end up with the right one.
Student 4.. This one is pretty good too, they've been pretty successful but eventually hey ended up with something that is kind of similar to how they started… they ended up with something simple. So maybe these ideas (the ones they iterate through), they're just kind of playing around and not having a clear.. They don't have a clear objective of what it is they really want to achieve at the end. They are just really excited or something like that. So yeah. I think student 3 I like this the most. I feel they are the most engaged. You can see each time they are doing something different. Looking from the beginning, in terms of the logic, they're trying out different logic here, it's all about their logic in their schematics. It's gradually improving so you can definitely see growth. They're playing around with the logic, not really necessarily different not just plugging in different things to try out different ideas but trying to hone in their idea with the logic using the same components. I feel student 3 has shown the most growth looking at this data.

ME: how would you recognise your own students in these approaches graphs?

My student match probably student number 2 or 4 typically. Then you get some students like student 1. But you don't see a lot of students like student 3. The reason why I say that is because a lot of students don't like to experience failure. And they're still dealing with that. You can find a group of students that is OK with experiencing failure, and still moving forward, still wanting to attempt more, and get progressively better, that's pretty good. But definitely students are typically more like 2 and 4. That's your average student.

So to re-rank, I would say 3, then 1, then probably 4 and then 2.

ME: If you had this in classroom available, in what way would you use it?

I think it's great. I don't really know how to say this, but we have Google Docs, and it's a great way to document what they are doing when they are doing it, because it has version history. I can literally go in there, and this is the SAM Labs version of Google Docs, where I can go in and look at it. I don't know if the timestamp is necessary from a students' view. But I definitely think they would appreciate the schematics, the screenshot of the schematics as they are progressing. So maybe like every time they are working on it or every day, it takes a screenshot you can kind of see their progression. Yeah, I think that would be super fantastic, if you had something like this. Not just for student, but also for teachers, with their progress and what their thinking process is.

ME: visualisations 3: blocks and connections

This is a really interesting data visualisation, I've never seen anything like this before. Based on this, as you can see, students 2 and 4, they have a base, which they are comfortable with. Every time they don't succeed, they like to go back to that base, that schematic. That's what I'm understanding just based on this visualisation here. Student 1 is coming up with new schematics, progressing, coming back to old schematics, but not that much, but always coming up with something new, new idea, new connection. They are progressively getting better, this is pretty good. And student 3 is the crazy student, they try different things, go back, and try other things. This is a really dynamic student.

Theme: trying out NEW things is associated with progression

I think what this tells me about the students' understanding is SAM is, it tells me, sort of, lets me take a peek of what it is that students are experimenting, with the different input outputs and the different connection blocks, and it tells me how many different types of logic and connects they are trying out. For example, you can see here, this student didn't use that many .. 2 and 4 didn't use that many connections, especially student 4. They have a few different pathways, but compared to student 3, I mean they are trying a lot of pathways and schematics. So this is what it's telling me: how much efforts are they putting in, in trying new things, explore new parts, new inputs, outputs, and coding logic.
More so with student 3 look at how many blocks they are trying out. Student 1 is playing with the logic, with a limited amount of connectors. This student is really trying to figure out the logic but student 3 is experimenting with a lot of different connectors because the connectors that he or she is using may not be working so, .. which is fine.

Visualisation 4: kept versus discarded

So this compares the schematics from the beginning, to the end schematic, the final product. Blue means that they kept that type of connection, and orange means they ditched it.
I think, for me, what you want to do, is get to something like student 3 here. Where blue meets orange roughly at the half-way mark. The y axis doesn't need to be high, but I feel like that gradually they are ditching the old and bringing something new because they are experimenting, figuring out what's right and wrong, and then boof, at the end, there it is. And then for student 2, they're just… they're not really exploring. I feel like this student is more like 'i don't know what to do, I don't have that many ideas, at the end they might have got an idea maybe from another student, and gone like, 'here, ok, here's my final product'. So that's what I think. And student 4 is just kind of like, all over the place in terms of..I think this is the one that they try, if I remember correctly, they try different inputs and outputs. So they were kind of a little bit excited, or really they just weren't focused on their end goal. I think that's the reason why you have a consistent like, new, and keeping and not keeping the same components. Student 1 here I feel like they are gradually growing.

Theme: In kept versus discarded, a gradual progression from discarded into kept seems desirable

Theme: as they explain, teachers are trying to find 'productive' versus 'unproductive' patterns from the visualisations - describe what might look like 'good' patterns or 'bad' patterns. Looking for what looks like 'productive' experimentation, although identifying it differently. However, they struggle to clearly identify them, most teachers differ in opinion, and it shows how hard it is to say 'this is good', and 'this is bad'. Because it is contextual, it is dependent on what the student wants and their goals… for example, it's true, Jack didn't really know what to do, didn't have an end goal until later in the project. But nevertheless, they started playing around with the blocks in order to GET ideas. And what's wrong with that? The data shows a lack of goal, the teachers are able to identify that in the data, and the decision on whether that is OK or not has to be left for a discussion between the teacher and the student - student explaining their rationale, and the teacher making a decision on whether this requires any intervention, modification or scaffolding or not.

Theme: teachers feel slightly uneasy about different visualisations sending slightly different messages about the same student - they expect consistency in what each visualisations sais about each student, and look for similarities and common threads between them. When these commonalities are discontinued between what they thought of the same student between different visualisations, they are confused and slightly set back. But for the majority, they try to construct what they see in each visualisation into a consistent narrative for each student that is kept across the visualisations. (eg: that's why the blocks across contexts visualisations doesn't really give much / confuses more)

ME: compared with the insights you gain in person from SAM projects in the classroom, how do these visualisations add or complement what you observe, if at all?

I definitely think these visualisations are extremely helpful for me. But on the other hand, I feel like… I'm a data guy, so I like this kind of stuff. But I remember doing data for a group of teacher and they are like .. they get overwhelmed by data so easily. Graphs.. Even the normal graphs like pie graphs, bar graphs or scatter plots, or whatever, they get overwhelmed super easily. So I don't know, if this was to be used as a tool, I don't know how you guys are going to make it super easy for teachers and students alike to kind of understand the data points. That's my only concern, how do you get teachers to be OK looking at this data. Because looking at this (the blocks and connections), how do you… 'oh my god, what is this?' looking at this graph a lot of teachers would be intimidated, wouldn't be able to interpret this right here. With the different circles with the different colors and lines, that's all they would see. But.. otherwise I find it very useful.

ME: any comments on what my improve that readability? What's most unhelpful and things that would improve these?

I think if you guys were to implement this, I don't think it should show any graph at all. Like, a student platform, or teacher platform that you login, and it tells them, based on this data, this could be the back end, and it spits out a number or percentage. It would spit out a percentage: engagement level: 80% engage, or something like that. Or students are improving / progressing and a percentage. They'll understand that metric. You can split it into categorise, however you want to categorise and associate the data to different categories, but that's the only way to get teachers to understand it. Teachers don't understand graphs.

ME: So is there any value in showing the journey as it is, without much interpretation? You identified lots of different dimensions, and they could be good or bad depending on what the student is trying to achieve and the context.

Yeah… I mean, I think if you show a progression…. If you were to show different versions of the schematic, that's fine..
But they just need a percentage to compare with other students, or standards, or something that's all what they're about. Anything beyond that, they're like 'I don't have time for this'. I'm speaking from first hand experience. I work with teachers that have that kind of mentality, they don't want to really wrap their heads around how to read data. They just need it super simplified, and have evidence. What is the evidence? The evidence are the different versions, and whether they progress or not, you can tell them that. Or they can conclude that

based on looking at the different versions, different teachers have different criteria, you guys can give them the right criteria, and give them a percentage, and they can say ‘my student is improving by 70%’, that would be something that you guys need to do. Because different teachers have different perspectives, and you guys need to give them some kind of numbers… give them that!

Theme: teachers don’t have time for anything else but super-simplified numbers…
But when looking at what informs those numbers, how they are reached, how many different interpretations there might be… all that complexity, there is no time for it!! Even if it’s there, it exists!!

Why don’t you guys find a way to … , you’re telling me it’s hard to standardise, but there’s also ways for students to, for even between a pair of users, to compare the schematics against each other. I don’t know ow you’d do that..I don’t know. I know that standardisation is all over the place, but I feel like there is some grounds to standardise some things. You can also present the data in terms of their schematics and everything, but I feel like if I were to see a number, it kind of gives you an idea of where they’re at compared to other students. But it gives me some kind of focus on what I need to improve on: do my students need to experiment more with connectors, or do they need to more inputs, or outputs, or something like that.
But I feel like all of that data is super useful to me, personally, I can look at it from my own lens in my one own classroom, how do my students compare to other students across the world who are also using SAM Labs? Just some questions that you can probably bring up with the SAM Labs team. I would be interested in looking at that data, and seeing how, how my students. That’s the standardisation that I’m talking about. I know some teachers feel like they have a different perspective, but there are certain criteria that we have all in common, like using connectors, and using inputs, outputs, and the variation of those combinations, I feel those are kind of like a standard based, and SAM can set a standard to communicate to all of us what those expectations are.

I want to really emphasise on.. , I mean open-ended is great but I feel like there’s a certain guideline, a certain level that we want our students to achieve. And it might not be at that time, but eventually the progression is part of the journey. They’re not here yet, so let’s say student 2, they need to improve on whatever they need to improve on to get to a certain standard, an average across all the SAM Labs students across the world. I think that’s all really fair to implement.

ME: That’s bollocks. Why would you want that? A comparison between my student and an average of all other students across the world?! Nah.

Teacher H

That’s cool. I’m totally stealing this idea. I’m doing this Japannese and Turmic unit, and I’d like to integrate all of this stuff, but I’ve always felt so uncomfortable trying to integrate with that unit. But I’m like if it’s more of like a quiz game, then I could do something like that, and it wouldn’t feel so inappropriate.

Visualisation 1: end graphs

I think the first thing that I notice is student 1 has more varied connections. As opposed to student 4 who's like 1 line all the way through. So I would definitely see student 1 as a higher version, because they're seeing the path and how the path can split. It looks like student 2 is the one time version of student 4. If I was ranking them top to bottom, student 1,3,4,2.

Visualisation 2: approaches over time

So this is just like student 2 (the first approach from student 1). Pretty much, except for the hold.

I wonder why this student decided to go with a proximity sensor instead of a pressure sensor. I guess it might work better in the game with the proximity.

I think student 3 is interesting because they tried a lot of things, they had a lot more that weren't valid, but I appreciated that they tried a lot of things. I think that's really great. Same with student 4, even though I didn't love their version as much, they did a lot of experimenting and had a lot of valid tries. Ohh, they started out with a button, 2 buttons I guess. That's an interesting way to start, with the goal being an axe, because somebody can choose not to push it. I also wonder too, sometimes in my class they'll have an idea, but then there's no available sliders, or buttons, and they put one in at the last minute.

That's interesting...(looking at 4), was this student was considering, could I make this with one line or even … I really liked the axe that I made so I'm going to do it two more times. It's also interesting that in their final example they took out the hold.

I think for me, in terms of student learning, because I like to see that they are trying lots of different things, I would say that now student 4 is probably my top choice, and fairly close student 3. They had fewer that were successful, but that have a lot of tries. And then probably student 2 and then student 1 at the bottom. Student 1 reminds me of those kids who are like 'well I know how to make it work, so here we go, there it is'.

ME: Do you find this view informative?

Yes, I love this interactive version, I can see each different version and how long they sat with that idea. To say like, 'oh, I tried this, it was OK, but then I pretty quickly moved on to something else'. And that they sat with an invalid idea for a while, as opposed to student 3 who… whilst they sat with something down here for a while that was invalid, they moved through the invalid attempts pretty quickly towards the end.

ME: I wonder how you account for the differences between students, given that they are going towards the same goal.

I think that student 2 and student 4 found the most direct route to make it happen. But I think student 1 and 3 put a little more… i think that thinking of different ways of making connections I feel that students 1 and 3 thought more about that. Because it's not a straight path through. Especially with student 1 having the warning sound, to add that extra layer to it.

ME: Do you see this kind of iterative behaviour in your classroom, and how do you associate what you see here with what you expect from your experiences in your own classroom?

I think this is pretty close to what I see in my classroom. I think my students a more like 1 and 2. They don't want to try as many different things. Which I think is actually mostly this year, my kids this year mostly want to find the path and get it done. Very right answered focused. Whereas in previous years there tended to be more behaviour of building, and tearing it down, and building and tearing it down again.

Visualisation 3: blocks and connection

Looks like student 3 really tried a lot, in a lot of different ways. Whereas it looks like student 4, they went with 1 path and they kept making that same connection a lot. And similar with student 2, they tried a few things but found something that worked and stuck with it a lot. Which could be good, they found something and then tried other pieces to go with it.
I love that student 3 is all over the place though. I think it's interesting that they… it's clear they didn't have a set path. They were ready to try something different. Even though they found things that functioned, but they wanted to see what else they could do with it.
I think that can be really great, and at the same time it can be like 'oh by gosh child pick a way and get it done!'.
But I think student 1, the more I see it, this was the kid that found a way to do it, and was done. Which I think is… even if their final graph seemed really sophisticated, it maybe could have been even more sophisticated if they had done more experimenting.

ME: Would this be something that you'd be interested to look at from your students in your classroom? In what ways would you find it helpful to use this view?

I was thinking, my students did a biography project this year. During reading and writing that had to read a biography and write about the person they were studying. And we integrated SAM by making a robot museum, it was really fun. I left it very open, I told the kids to.. We had a class that was 'study what the character says and does to learn more about them as a person'. So I told them they needed to study what their character does, because they needed to create this moving model of their character. And I think this view would be really interesting, because I'm thinking of some of my students who… so I had two of my students who chose to use micro:bits first, and they played around for a little bit, we talked about how this was something we had less experience with and that I could help, but that we hadn't done it a lot. But they gave up pretty quickly. And it would have been interesting to see what connections they were making, and what connections they were missing, before they switched into something else.

Visualisation 4: kept versus discarded

This actually makes me feel a little bit better about student 1. Because it looks like they tried some things and got rid of some things, as opposed to picking one path and sticking with it. So I think this view is really good in conjunction with the other ones, from the other ones I might think 'oh this sophisticated one they just knew, they didn't try anything', this show they did try some things. It's also really interesting with student 4 that they were still discarding right until the nitty gritty at the end, and adding new blocks at the very end. But I think students 2 and maybe even student 3 the most, definitely student 3 the most it's interesting that they had a lot of trial at the beginning, but as it got close to their final solution, they were discarding fewer blocks. So they were really making a plan and finding what worked with it, as opposed to just trying out everything. Which looks a lot more like student 2, was trying a lot of things just to see what would happen. Student 3 looks a little more mindful about what would make the most sense, which I think is really powerful.

ME: If you were to use these in your own classroom, in what way would you see practically using such visualisations in your classroom?

In a couple of ways. I'm a big fan of sharing data with the students. So I think showing the kids this view, and saying 'what do you guys think is going on here', I think they would have the same kind if insights like 'oh, that person didn't try as many things, but that person tried a LOT of things.' and then talking about the pros and cons of that. And i think for me as a teacher, if you had more than one of these projects, to look at how the kids change throughout the year, and see if they are continuing to try new things, or do they get lore like 'I've learnt now, I'll just do it', which is maybe not as much what I would want from them, I would want more of the experimenting and the trying, to see what would happen over time.

Visualisations 5: kept versus discarded valid/invalid

This one is a lot harder to interpret than the previous one. But that might be because I really want to read that list on the left hand side. I think what I'm noticing is that students 1,2,3, they … no.. cause student 3 has a lot of grey down here. So student 1 had a lot of trial and error, and once they got towards the end of the project, they mostly made connections that worked and that they liked and kept. Student 3 a lot of trial and error, but even towards the end of the project a lot of things that weren't quite working. And kind of similar to student 4 but they also look like they had some lines that worked and 'I'm going to keep it going the whole time'. But discarded a lot of things that were working for hem which is interesting. But I think what I like about Student 2 is that they did find something that worked, but didn't discard it, tried some other things that didn't work, discarded that, and then… I'm curious of the things they decided to do.. It looks like they are similar.. Which i think is really nice that they were like 'Yeah, this works, I'll try something else, but went back to their first plan.'

Visualisation 6: blocks across context

I'm really coming back to my love for student 1 and student 2 with this one. Because it doesn't look as much as like they were trying one thing, 'this works, I'm done'. It does look like they've tried a lot of different ideas. Even if they saw 'oh this does work', let me try using something else, and even making it a little more complicated along the way. I think it's really interesting that student 2 started out with fairly complex patterns, but then ended on a very simple one. So it's interesting that they came back down to just three pieced. **So I would be interested to ask this student what they liked and didn't like about these first two. And why they decided to change. Which I think adds a nice language piece when you're assessing kids 'why did you make that choice?!'.**

Student 3 still looks a bit safe.. maybe is the way. They started something, and then went very basic, and then kept it pretty basic towards the end.

I wonder with student 4, whether they were worried it being too complex, cause it seems like they made it simpler along the way. Or if maybe, as they practised playing the game, cause I noticed they went from inverse to hold, and then to just removing that altogether. I wonder if while they were playing it was just not… fast enough, or fun enough, and they needed to make it a little snappier. **Which is another language component to ask that kid about.** I have a class full of language learners this year, so **I'm always thinking about 'what questions can I ask them to make them say thing!!**'.

Theme: the teachers might read too much into the visuals, make assumptions, and the visuals might be sending the wrong messages. Nevertheless, they communicate what they teachers value - the visualisations are holders for thinking about iterations, trial-and-error, and artefacts to think with and expose thoughts about what the teachers are looking for or value. Whether the visualisations actually show that is a different matter. But they are intermediate artefacts which allow for teachers to voice what they would want to see, and what future iterations of the visualisations should show accurately if they were to be designed for classroom usage. They almost act as a 'wizard-of-oz'.

Theme: the ways in which the visualisations didn't transmit the messages they were designed for: in the blocks across context, the teachers still expect validity to be shown, and still expect the circuits to be on a timeline. In addition, they continue to rate the overall students' performance, despite the fact that the visuals only show a subsection of experimentation - this might be due to the order in which the visualisations were shown, or the fact that it was the only visual which only showed a partial section of the childrens' experimentation.

Theme: tension between theoretical ideas (mistakes are good, simple designs are just as valuable as complex ones), and practical ways in which the teachers interpreted the visualisations - complexity is still seen as a positive thing throughout, and a simplified end output is questioned as 'problematic'. What does this mean for data analytics? That these are complex ideas that sit in tension not only in pedagogical research, but also in teachers' perceptions, and that it is difficult to converge around a single way of interpretation, solely from the data. The students' goals and intentions need to come into it, as teachers point out time and time again, to verify whether the decisions are evidence-based and justified.

ME: Compared to the type of insights you might get in your own classroom normally, how to the visualisations add or complement what you would normally observe / track?

I really like, especially this view (the approaches over time), because typically in a class of 30, I only get to see then end result. I don't get to see the pieces leading up to it. I especially have some really nervous and shy kids. If they think they've done something wrong, they don't want you to see it. I actually, my favourite stories is one of my students, he is a language learner, but he's been speaking English since kindergarten, but still very low language learner. And one of the ambassadors from SAM came into my room one day and we were doing a lesson on MorseCode whilst we were studying Western expansion, and he had coded his. But instead of beeping, he made a farting sound, and he was not going to share that. It was not happening. So we had to talk him into it, and he's like … 'ok..', and we're all just dying, it's so funny. But if there wasn't someone standing there, coercing him into saying that, he never would have done it. So I think being able to see this view and say 'hey, back there when you did that, that might be really fun to share'. It was so cute. By the time he did share it and we were all just laughing hysterically he was finally like 'Oh, ok, this is alright'.

Theme: the approaches over time is the one visualisations which has potential to be used in the classroom. The rest are informative about the iterative design process in general, but unsuitable to be used as they are for classroom analytics.

ME: It's the same goal, but different approaches. Is this what you see in your classroom, and how do you deal with that in the classroom in terms of supporting different solutions?

I've also started with the SAM curriculum which is very guided, and kids can do it, and it all looks the same, and they feel really successful and I think that's really wonderful… but then when we've done the more open-ended projects and they've had to think about it more, without a real answer.. Even using the curriculum from SAM and not showing the how-to part, and say 'this is what I want you to do, make it happen, I'm giving you 15 minutes and we'll see where you're at..', I think it's interesting to see the kids, anecdotally, who's willing to kind of tought it out and figure out a solution as supposed to kids who are really quick to give up when they can't get it to work. So, some ways that I've found success with those: sometimes they can pick their partner and then it's always.. You get what get. And sometimes you have a group that they both do it and it's fine. And sometimes you have a group where neither of them are very strong problem-solvers, so then it's a struggle. Other times I do try to partner a good problem-solver with somebody that's maybe a little quick to give up. And to get a good record of what kids are doing, or what they had done rather, we've been using a lot of videos. So we've been using a lot of SeeSaw, and record what they did. And I go back and watch them, to see kind of what they were thinking, even if I'm not able to check in with each kid as they go. Which has been really helpful. I had never really used SeeSaw until this year, and I was like, 'I don't know, I don't know if I'll like this'. But looking at their biographies project and having them talk about .. and not just to say 'oh I tried this, I did this..', but using the vocabulary of 'I chose this input and connected it to this behaviour so that this would happen as an output..', and hearing them use that language was big and important.

ME: Yes, the kids in this class also used SeeSaw and the teacher encouraged them to document their changes.

I was just thinking, as you were saying that, they could be doing a screenshot of what did, and just a quick sketch or write-down of 'oh, I changed this because of this', and then later they could upload that all to SeeSaw. And that way, I could see that record too, which is really… that's a really cool idea.
They can be reluctant to do it, especially if they feel like 'oh I did it wrong, and now I have to tell her I did it wrong… not that!!'.

ME: In what ways would you improve the visuals we've seen?

I'd actually really to see both this one, where you can see the actual changes, but then also the kept versus discarded where you can see they've taken things off. I think those two are my favourite views. Just to see what kind of what the differences were, and the number of tries is a big one, the number of attempts I guess.
I liked to see the connections too. I can't think of anything that I'd like to see that I'm not.

Teacher I

I had trouble with that one <the context video>. I guess because it was more like a sketch of, it seemed more a stream of consciousness to me. I know that as a teacher.. Teachers might feel lost seeing that, that would be my first response. I thought the presentation of the activity was .. Sketchy. It didn't really..

<I explain exactly how the video was used in the classroom>

Ah, ok. Let me see the students too then.

Visualisation 1: end graphs

It depends, I have a bit of a funky assessment criteria. Cause I'm teaching, my entire assessment criteria is based on Stanford's Designing Thinking cycle. What I would .. I wouldn't actually look at the final product to mark it, because that means nothing to me, it's the progression that got them there. So for this, in terms of their prototype phased, I would mark this as not particularly high, because I didn't see 'I first tried this, and then this, and it didn't work, and then I asked for help and then I rethought my idea and then…' it's sort of a rich process of iteration and feedback is how I assess this kind of thing. I wouldn't look at a program and go 'oh, that looks complicated enough, you get an A. Or our Highscool I grade with A,D,F but in the middle school I grade with the Standard-Based Grading thing.
Yeah, you want to get to the right answer, so other teachers might grade this based on solely on the final result.

Just based on this final implementation, I guess with computer programming you want to see … it's kind of a contradiction because on one hand you want to see students solve a problem most efficiently, but then you also want them to show evidence of skills and competency and computational concepts. In terms of simplicity, Student 2 probably solved the problem the fastest, but then Student 1 is showing a bit more logic as well as Student 3. So from the logic, Student 1 and 3 are better, but from a simplicity point of view, Student 2 and 4 are better. So it really depends on the problem they are solving and whether or not this meets the solution. In terms of just like, demonstrating coding, they are like, I guess, student 3 and student 1 show the most control structures, or algorithmic thinking.

I'm teaching an Advance Computer Science class at the high school level, and the students are working on their 'Create Performance' task, it's a portfolio thing, that they submit to the College Board of the US by May. Because of Covid their multiple-choice test was waved, so their whole grade is based on 2 projects. One a research project and one is a coding project. But in terms of their grade, they have to show their use of abstraction. So they can write a great program, but if they don't write any functions and code re-usability, then they won't get full marks on that strand. You have to show the use of data structures, so lists or arrays. They have to show evidence of process, so I'm making them all do their process journals over the course of developing their coding projects, and use of control structures, if statements, boolean logic etc. So there are like, in terms of 'Am I done? Does my project work?', they have to show evidence that they can use these 4 strands of computational thinking in their program.

I don’t know, I think Student 1 and 3 are basically equal. I wouldn’t put one above the other. And then maybe student 4 cause they tried more… maybe there was more iteration and experimentation with student 4 than student 2.

Visualisation 2: approaches over time

That’s pretty cool. I kind of get where you’re going with these, even just looking at the non-interactive version file, already you see evidence of iteration. So student 1 had an invalid attempt, and then only got things to work and didn’t make mistakes.. Whereas Student 2 has a nice mix of green and grey.. Try something, it works, let me try something else, oh it didn’t work, let me try to fix it, oh it worked. And then Student 4 barely make any mistakes, and there’s a whole lot here with Student 3. You’re looking to see evidence of prototyping and making mistakes and getting feedback and…
Student 3, Student 2, Student 4, Student 1 would be my ranking.
I know I can look at the individual code of each approach, but I can see the graph <without hovering over the attempts> and get a sense of who really got stuck in and messed around and tried different things, and some kids got complacent and just tried a few things and stopped ‘oh look, i’m done’. It drives me crazy when kids are like ‘I’m done!!’ - what do you want, a cookie? What’s going on here? Do you want to stop class and celebrate you rapid achievement in front of everyone?
You don’t want to discourage kids, make them feel like they are on a hamster wheel never getting anywhere, but at the same time this means you have a chance to learn more than other students, more time to experiment and prototype, instead of just stop and not to anything. That’s why differentiation in learning is so important.

I don’t know these students, so I was teaching them and assess them, then I would, you know, so if I had a student that was weekly performing, and I saw Student 1 and that was a weaker performing student, I actually might give them quite a lot of encouragement for that <what they did in approaches over time>, because clearly they are working on it, and clearly they worked over time on it. Because in some sense, I mean, there’s a real range of abilities that I see. So I simply can’t hold students accountable to the same thing based on their learning support needs. But if I saw student 1 and I knew he was capable of a lot more, I really would rip into that student, in a nice way. I wouldn’t be happy with students’ 1 performance for a student I know has experience and should be pushing themselves further.

<I tell him that these are 4 of the highest’ achiving students generally in Karen’s classroom>
Interesting, because of those high ability students, not all of them put in the same effort. And you also want to reward curiosity, so the more students try to experiment different things, the better. And celebrate failure, it’s important.

Visualisation 3: blocks and circuits
34:00

Teacher J

I sometimes find that when providing students with ideas of what to include it will narrow their ability to be creative in the process of what they might develop, because all of a sudden they all think that that is the only way of creating something. So everyone in the class will start creating or altering the same thing.

It seems like there was a lack of any structure. It was very much, like you said, open-ended. But you can have open-ended projects that have a lot of structure to them and a lot of requirement. This is extremely open-ended. The conclusions that you draw are tied to, not just the use of the SAM materials, but also to the way in which this activity is structured.

So whenever I create an open-ended project, I have to first consider how I'm .. well, first I'm going to consider what content I want them to understand, and then .. this part is understanding by design, like I'm going to figure out how I'm going to get them to demonstrate, or how I'm going to get them to demonstrate the understanding of that content.

Appendix J

SAM Labs Introduction into Schools

SAM Labs Autumn 2017 Code Clubs - main findings and conclusions

The SAM Labs Autumn Term 2017 code clubs at Mowlem Primary School, Elizabeth's Primary School and Keble Prep School were setup with the primary aim of obtaining feedback on the SAM Labs lesson plans in a live classroom environment. The main questions were:

- Do the lesson plans work as one-hour long activities in a classroom made up of 20-30 children?
- Can the activities be understood and finalised in a one-hour lesson without significant pre-lesson prerequisites or post-lesson extensions for the students?
- Can the lessons plans be followed as they are without additional clarifications or modifications and with minimal pre-class preparation from teachers?
- Is the content of the lesson plans relevant to the curriculum and appealing for teachers?
- Do the students enjoy and engage in the activities set out in the lesson plans?

The code clubs were also the first sustained, long-term presence in schools conducting observational research around how the SAM Labs kits can be integrated into the classroom. Additional insights were gathered around how the kits are received by students, how the kits can be used most effectively, how appealing they are to teachers, the main challenges in introducing SAM kits into the classrooms as well as general usability issues. As well as running the lessons, informal interviews were conducted with the teachers and school representatives involved in the setup of the clubs as well as with the children, reported as findings in this report. Given that the research was conducted in primary schools only, this report makes reference solely to primary schools. Whilst some findings are mostly likely transferable to secondary schools, there were not validated in any concrete ways.

Introduction into schools

The lessons were offered as free of charge code clubs led by SAM 'experts' for two reasons:

1) As SAM representatives, it was considered important and valuable to experience what it takes to use SAM in a classroom from a teacher perspective (as much as possible considering the lack of teaching qualifications)
2) Schools were much more likely to accept ready-made, 'all-included' sessions rather than having to put in the time and resources to learn about SAM and prepare to lead the sessions themselves
3) The code clubs were offered as fun, informal yet educational sessions with no official evaluation, similar to existing 'maker spaces' or Raspberry Pi workshops schools are already familiar with from different contexts

Two of the schools - Mowlem Primary School and Elizabeth's Primary School had not worked with SAM and did not own any kits, however amongst the reasons for accepting the running of

the code clubs included primarily a desire to introduce more computing into their schools, an appeal for trying the increasingly popular concept of 'code clubs' within the boundaries of their own schools, the opportunity to learn more about the kits and getting full support in adopting such a kit within their school.
Keble Prep already owned and had been using SAM Kits for almost two years, however the clubs were still led by the SAM representative with the aim of testing the not-yet-released lesson plans.

Both Mowlem Primary School and Elizabeth's Primary School have said that it is highly unlikely they would have took on the SAM kits on their own, even at a much lower price.
The major challenges they are facings are:

- Lack of funding to purchase the kits in the first place
- Lack of technical expertise viewed as essential to understand how the kits work but most importantly the computing concepts behind the lessons using the kits
- Lack of time to undertake what seems like a steep and costly learning curve of using the kits, understanding the computing concepts behind them and the preparation needed to embed them in the classroom against the curriculum

These fears and sources of anxiety and reluctance in adopting computing more seriously and at scale in schools have been the focus of much research, hardly unique to Mowlem Primary School or Elizabeth's Primary School. There is a lack of confidence amongst class primary school teachers, who are not technically trained, to take on what appear to be complicated concepts, learn them themselves well enough to prepare teaching content and deliver in to their students. It is a daunting task for primary school teachers, who do not typically specialise in any field but are generalists teaching the basics of many subjects, to take on what still appears, rightly or not, a technical specialisation for which they are offered no support or training on. The reality is that most primary school teachers have no computing background or knowledge, rarely interact with computers beyond basic software general usage, which poses the huge challenge of them teaching something they don't know themselves.

Teachers have been long requesting the budgetary and expert personnel assistance to help them integrate the much needed and requested computing content in schools, and comply with the curriculum requirements.
Where such support can be sourced, the schools are successful at training their teachers and incorporating computing into their curriculum. At both Keble Prep School and Shacklewell Primary School (an additional school where no code clubs were run, but were previous small-scale user testing took place), computing was introduced with the help of an expert - a technical individual, with or without specific teaching qualifications, who is able to support the teachers in their own learning as well as in their teaching. Both schools were able not only to use such expertise throughout their journey but the school also provided extended support, giving teachers the time and space required to learn and embed computing into their teaching.
The two main requirements teachers have to be able to successfully teach computing are:

- Technical expertise - and not just external training but embedded in the school to support the day-to-day questions and practical happening of the lessons
- Support in time and resources for teachers to take it all in and adapt it into their teaching

The learning curve and full journey towards a comprehensive integration of computing, following the curriculum, into a school is a lengthy and intricate process, comprising of many changes being introduced - new knowledge to be acquired by teachers, new subject to teach and add to the students' portfolios, new tools to integrate, new processes to be designed and adopted by the schools. Provided the integration is sustained and fully supported at the school leadership level, the average timescale for a school to reach a point where they are able to confidently say they teach computing as an integral part of the curriculum is about 2 years. For many primary schools yet it remains an extension to the main teaching, comprising of limited and basic activities using freely available tools and resources, as it is the case for Mowlem Primary School or Elizabeth's Primary School.
Of course this transitional period is being undertaken by more and more schools, and will eventually be a problem of the past - as more and more technically-savvy teachers enter the work-force, and more and more schools being forced into providing the necessary support for teaching computing as a main part of their educational offering, the lack of expertise amongst primary school teachers will decrease - however the timescales to this is unknown and given the present challenges unlikely to come particularly soon.

For Keble Prep, the SAM kits were a big part of that 2-year transitional period, being one of the main tools used as an entry-level kit into the Technology Design classes. Keble Prep is singled out given its proactive approach to SAM - it was the school who adopted the kits on their own accord, which gives valuable insight into the drivers behind acquiring SAM without it being actively targeted and most importantly, without specific support from SAM 'experts'.
It was Karen, the Director of Digital Learning as well as Computer Science teacher at Keble Prep, who found and bought the SAM kits. At the time of the purchase, she was already teaching basic programming using Scratch and Python. Her purchase was driven by a desire to present students with tangible robotics, which they can correlate to their software programming and extent to the physical environment. In addition, she was keen to enhance her Technology Design classes with physical computing kits which allowed the children to take more control over the design of their artifacts, in parallel to other tools like Lego and 3D printing. Critically, she was attracted by the ease of use, low-level entry required for understanding and integrating the tool into her computing classes, as well as the open-ended capabilities. Karen was specifically attracted by the possibilities of her students engaging with the tool creatively, thinking about what is possible to build and making their own designs according to their own interests and passions. Importantly, Keble Prep School is a private school, with significantly more financial resources than most state-funded schools, who can more easily afford to purchase the SAM kits, try them out, take the time to learn and integrate them into the classroom. Ultimately teachers cannot teach something they don't know. Teachers can either undertake the training to learn more about computing in order to be able to teach it, or learn it alongside their students - a concept with which teachers are often uncomfortable with.

Her journey is not unique - given the wide community support for Scratch, it being free of charge and its direct and close connection to the curriculum specification, it is the entry point into computing for many primary schools. However the increased interest in 'makerspaces', the perceived benefits of such practical environments encouraging attitudes of 'creators not consumers', as well as the need to cover hardware-based curriculum related topics push the need for physical computing kits to be acquired and used in schools in addition to software programming.

A further problem impacting the introduction of computing into schools is that given its still relatively recent introduction as part of the curriculum, there is still a lot of research being undertaken around the best ways of teaching it depending on the students' age, background, contexts, abilities and how it relates to other subject knowledge. This remains an on-going challenge, beyond the 2-year teacher&school-accomodation phase, which requires teachers to continually change and adapt their teaching in trying to find the best tools and content to use.

This is where one of the main challenges for SAM appears - what problem is best to focus on?

- A product which focuses on assisting schools and teachers in their accomodation phase to introducing computing in the first place?
- A product which focuses on being a great introduction tools for students into computing irrespective of the teachers' technical expertise?

Whilst the two aims are related, and they both need to be accounted for, they are not entirely the same, and they lead to overlapping yet different outcomes - one which is focused on teachers' needs and the other which focuses on the students' needs. One is much more targeted towards relevant materials and content for teachers to use in their classrooms to support their own learning as well as the students', whilst the other is more targeted on the efficacy of SAM as an educational tool - what exact learning does it promote and how can SAM be adapted to maximise those learnings entirely through the lens of the learners.

SAM educational value

More or less unanimously, when asked about the perceived/potential/expected educational benefits of the SAM kit, all four schools' answers focused on similar ideas:

- SAM being an easy introduction into computing, suitable for young children, starting with Year 5 students
- SAM being a suitable tool to use part of the technology design classes and promote computational thinking and making skills
- SAM being a good tool to embed logic and coding concepts in fun, creative, practical projects
- SAM being a relevant tool to engage students in problem-solving critical-thinking activities

The increased push towards promoting '21-century' skills - communication, collaboration, creativity, critical thinking and problem solving - have pushed the computing community to think long and hard about what kind of teaching they should be promoting - following into the footsteps of previous subjects, with a high emphasis on content knowledge and teacher instruction, or perhaps a more child-centered approach, where students are allowed to take more control over their own learning, adapt it according to their own interests and passions, engage in creative collaborative tasks of their own making, encouraged to learn from their own mistakes and adapt their own learning by knowing their own strengths and weaknesses, with

the teacher in a more supportive knowledge-expert role. Such ideas are steeped into constructivist educational theories introduced by psychologist Jean Piaget which remain the basis of modern educational research. The main shift consists of a fundamental rethink of how us as human beings learn - and it is not by taking in knowledge passed on by others (teachers instructing students), but by constructing the knowledge ourselves with the help of the tools and people around us.
However this shift leaves educational products such as SAM Labs at a crossroads between traditional teaching and evaluation methodologies still predominantly used in a majority of schools, and the emergence of new methodologies yet under-developed and uncatered for in the mainstream teaching and evaluation practices.

Specifically, SAM in its current form can support open-ended, exploratory projects which can be conducted within one-hour long activities or over longer periods of time (eg: a whole term project rather than a single lesson), to be embedded with other subjects such as maths, physics, biology or even history and arts. Given its low-level entry point which allows any user to very quickly get up and running with its basics functionality, the SAM blocks are well placed to be treated as physical computing kits to be integrated in any subject, and to empower any physical artifact with 'smart' behaviours. In fact it is exactly these properties which encouraged Karen from Keble Prep school to acquire it, and has progressed in this direction through term-long projects such as designing an intelligent board game using SAM and 3D printing to help with history revision. Such learning activities are hardly present in today's classrooms and there is little incentive to encourage the proliferation of computational capabilities to other subjects at the moment. This type of learning is highly encouraged in modern educational research, however it represents a major shift from traditional school setups. A majority of teachers, still lacking knowledge around computing concepts, need the lesson by lesson comfort and steady progressive reporting, even if that often sits at odds with modern educational research.

This shift presents a secondary major challenge for the SAM product - to what extent to abide by the rules and needs of current educational practices, and to what extent to support and be a part of the progressive movement towards novel tools and methodologies.

Code Clubs Outcomes

Student Groups setup

School	Student Class	# Students	# Code Clubs	Available Equipment
Mowlem	Year 5	30	9	12 Windows 7 Shared Laptops
Elizabeth's	Year 6A	25	5	10 Windows 7 Shared Laptops
Elizabeth's	Year 6B	25	4	10 Windows 7 Shared Laptops

Keble Prep	Year 7	5	7	Individual Macs

Normal lesson

1) Enter classroom, greet students
2) Students would usually be setting up their computers, logging in and getting ready to receive the blocks
3) Share blocks & bluetooth dongles *(if required)*
4) Introduce activity and ask prerequisite questions *(do you know what …<morse code>... is, what can you think of when I say …<smart house>..., what are the components which make up … <a camera>..., etc.)*
5) Identify Step 1 of the activity *(ask questions and get the students to arrive at it as much as possible - eg: If I was to do this, what would I do first? If I wanted this, how would I achieve that in SAM given these blocks?, etc.)* and get all students to achieve it in SAM
6) Identify Step 2 of the activity *(ask questions and get the students to arrive at it as much as possible)* and get all students to achieve it in SAM
7) Etc. - same until the last step of the activity
8) Reflect - what did you achieve, how did you achieve it, what are the different approaches amongst the different groups, etc.
9) Showcase - get one of the groups to showcase their result

Setup

Overall, the SAM blocks were easy to get up and running with. The children quickly picked up the preparatory tasks: opening the virtual app, logging in, pairing the blocks and dragging them onto the canvas. Whilst these actions didn't always perform smoothly, the children knew what they had to do and easily remembered the steps from one lesson to another. Amongst the 4 different groups of children, on average it took 1-2 lessons for children to remember the setup steps, and follow them on their own without assistance or supervision, provided no unexpected behaviours occured.

The time it would take a student to get setup with SAM would vary between about 4-5 minutes in the first one-two sessions, to 1-2 minutes in the subsequent sessions, provided no technical issues occured. These timings were regularly achieved in the Mac-based Keble school environment. However, given that two of the schools used Windows 7 laptops which were often slow and problematic, even the logging into the SAM app, before any pairing, could take up to 10 minutes. Following that, in the 30-student Windows 7 environments, pairing could take up to 15 minutes for all students to complete. Some groups would achieve it in the 1-2 minutes when no issues occured, but these groups were a significant minority. The Windows 7 bluetooth pairing process proved problematic in a majority of instances - over 70% of the students would experience some pairing issue each lesson, providing a frustrating setting up experience in most lessons. The children quickly picked up on the troubleshooting steps however, and even if the time it took for all students to be setup remained to up to 15 minutes, the amount of assistance required by myself reduced dramatically, students being happy to try and fix the issues themselves, persevering without giving up.

The only times when students did give up were when they encountered technical pairing or connectivity issues which couldn't be solved after 2-3 attempts. The children would never give up quickly, they would persist in trying to resolve the issues by restarting the computers or moving away from other pairing teams to focus the bluetooth connectivity on their own blocks.

Engagement

The ability to, more or less instantly, create a basic circuit linking a button to a light up and seeing it working in practice held immense value. Even if not all children would complete the activity in a one-hour lesson, or understand the whole circuit of a complete artifact, all students would end up creating something. This allowed children to keep their enthusiasm throughout the lessons, knowing that regardless of whether they could complete the final artifact, they could definitely achieve something. In addition, this allowed children to approach every lesson with a positive attitude - there were no efforts made to get children to at least try and build something. The engagement and the attempts came naturally, without any prompting. The intention to succeed was there, every time, in every lesson, week after week, and it didn't fade throughout the semester. The students persisted in their tasks throughout the code club hour, rarely getting disengaged or distracted by something else.

The physical nature of SAM blocks was another aspect of paramount importance in the code clubs. This persisted beyond the novelty effect, which, especially with Keble students who were familiar with SAM from before the start of the Code Clubs and some of the children had worked with the kits for over a year, had worn off significantly by the time of the last code club. The fact that the children could physically play with the blocks, create tangible behaviours which they could see in action, touch and feel (motor wheel spinning, light turning on, press of the button, press of the pressure pad, etc.) held immense value. This contributed to the fascination the children had and maintained for the its, the engagement their maintained throughout the code clubs, and the persistence with which they approached every task.

As soon as I would walk into the classroom, the children would greet me and offer their help in sharing the SAM blocks around to the different groups. They were extremely keen to get their hands on the blocks more than anything else - by this point they hadn't opened the SAM app, they didn't know what the lesson would consist of, some wouldn't even have laptops in front of them yet, but the eagerness to get the blocks and have them on their desks took priority over anything else. The students were particularly enthusiastic about trying new blocks which they hadn't used before, but even on weeks where the same blocks were brought in repeatedly (the car equipment was taken into the schools during 4 sequential lessons), the children were still just as excited to receive the blocks and start using them.

It seemed that both the physical nature of the kits and the low entry to making something basic work, taken together, gave the children full confidence that they could make it work unanimously. The two aspects cannot be separated - the virtual only did not excite or engage children nowhere near as much as put together with the physical blocks, and had it been any more difficult to get a very first prototype working the anxiety and doubt whether they could even understand it at all would have taken away their positive attitude.

The target of the children's enthusiasm changed over the course of the semester - if at the beginning the students would be eager to try the blocks for themselves, play with them in whatever ways they saw available, and investigate them as far as they could on their own, this changed as the lessons continued. By the third or fourth lesson, the students became more targeted towards specific goals. If in the first couple of lessons they attention was scattered and whilst engaging with SAM, they would find it very difficult to stick to particular tasks, as the novelty worn out the enthusiasm remained, but the focus changed.
This impacted the preparation of the lessons with the group of students who only started in the middle of the semester. The first two lessons had little content, focusing on the absolute essentials: SAM setup, inputs->connections->outputs structure and basic behaviours. Going much further in the first 2-3 lessons would have been counterintuitive, as the students were absorbed by the kits and wanted to play with them on their own, exploring their functionality in their own way.
By lesson four, students would become more interested in the specific lesson objectives - what exactly are we building today? How can you make the same blocks behave differently? How can you enhance the behaviour?...which allowed me to progress through more complex graphs involving more of the software blocks. The engagement moved from the fascination of the physical blocks themselves to the manipulation of the behaviour of these physical blocks.

At times, due to broken blocks or not enough blocks to share around all the groups, I would encourage children to use the Sleeping SAMs to create similar circuits and to think of the same problems, which was never effective. Using the sleeping SAMs was never a suitable replacement for the tangible, sensory experience they would get from the physical blocks. Sleeping SAMs don't react - because they are not actually on, they wouldn't activate on the screen similar to connected blocks which can be activated on screen as well as physically. However the static state of the sleeping SAMs does not account entirely for the lack on interest in using these on their own - sure, it probably played some part in it, but the distinct lack of the physical block to have in their hands, feel and sense was critically what made the difference.

The engagement the children maintained with SAM cannot be overstated - both in terms of its sustained existence, but critically in terms of its contribution to the success of the lessons - other educational tools fight very hard to get that kind of enthusiasm from children lesson after lesson, and during the code clubs, the SAM Kits certainly achieved that. The impact of this engagement on what the children achieved is obvious and significant - it is common sense that the more engaged the children are with SAM, the more comfortable and confident they become in using it, therefore the easier it is for them to pick up the ideas SAM is designed to promote.
The engagement levels is not a measure of the educational success of the code clubs. Engagement does not lead on its own to acquiring computational skills or achieving the learning objectives of the lessons. Whilst it is feasible to assume the children's' engagement played some part in acquiring some computing skills and achieving some of the learning objectives, these were a lot more dependant on the effectiveness of the tool and the lesson plans themselves. The effectiveness of the code clubs towards their educational goals is discussed separately in this report.

Of course this must be taken in the context - these were free code clubs with a loose structure, where children were given the freedom to take their own approach, for children of a young age, without the usual pressures of learnings evaluation or failure repercussions - which, if changed, could impact the engagement levels as well.

Lessons preparation and activity sequence

The preparation of the lessons throughout the code clubs was a very interesting experience on its own. Having to prepare what activity I would follow each day, how it would build on what had been done previously, and what new elements are relevant to introduce was an interesting and eye-opening challenge. This feeds directly into the feedback around the lesson plans currently available from the SAM Education website.

The lesson plans followed throughout the term are as follows:

Date	School	Lesson	Aims	Completed?
28/09/2017	Keble	Reaction timer	As per lesson plan	3/3 groups
29/09/2017	Elizabeth's	Basic Car	SAM setup Inputs->Connections->Outputs Basic car moving forward	8/8 groups
03/10/2017	Mowlem	Morse Code	As per lesson plan	3/8 groups
05/10/2017	Keble	Buggy Tag	As per lesson plan	3/3 groups
06/10/2017	Elizabeth's	Super Selfie	As per lesson plan Camera Block Logic Gate	6/8 groups
10/10/2017	Mowlem	Alarm System	As per lesson plan	4/8 groups
12/10/2017	Keble	Car Racing Ground - open-ended challenge - what can influence all the other cars on the race track	Generate new ideas of using SAM Use new blocks	2/3 groups
31/10/2017	Mowlem	Car Start/Stop + Speed	Hold + On/Off Blocks Interval + Counter Blocks	3/8 groups
07/11/2017	Mowlem	Car Left / Right Car racing ground	Multiple Inputs Increasingly complex graph - added behaviour	3/8 groups
09/11/2017	Keble	SAM blocks combos - open-ended challenge - Using Switch+Interval / Logic Gate+Counter / Hold+Inverse	Generate new ideas of using SAM Use new blocks	2/3 groups
10/11/2017	Elizabeth's	Car racing ground - finalise from last time	Full car: left, right, stop, start, forward, backwards Increasingly complex graph - added	7/8 groups

			behaviour from last lessons Race	
14/11/2017	Mowlem	Car Forward /Backward Add Light	Light Block Multiple Inputs Increasingly complex graph - added behaviour	5/8 groups
17/11/2017	Elizabeth's	Started with the new group 6B - new start, build the starter car	SAM setup Inputs->Connections->Outputs Basic car moving forward	8/8 groups
21/11/2017	Mowlem	Super Selfie	As per lesson plan Camera Block Logic Gate	5/8
23/11/2017	Keble	All directional car using 1 slider and 1 button as inputs for all behaviour	Minimise blocks used to achieve something Alternative ways of controlling the car	3/3
24/11/2017	Elizabeth's	Car Left / Right Car racing ground	Multiple Inputs Increasingly complex graph - added behaviour Race	8/8
28/11/2017	Mowlem	Smart House 1 - Fire Alarm	Heat Sensor Alarm System	4/8
30/11/2017	Keble	Reverse-challenge: Show flashing light graph and tell me what it is	Reverse-engineer a graph - from the graph alone, tell me what the behaviour is and what the artifact might be - it was a flashing light powered by movement	1/3
01/12/2017	Elizabeth's	Smart House 1 - Fire Alarm	Heat Sensor Alarm System	5/8
15/12/2017	Elizabeth's	Smart House 2 - Santa is coming	Light Sensor Tilt Multiple Sensors Increasingly complex graph - added behaviour	4/8

- ### Do the lesson plans work as one-hour long activities in a classroom made up of 20-30 children?

Given that, as a third party to SAM, I was not able to easily acquire the SAM blocks needed for the various lesson plans already existent on the SAM website, I was forced into making up some of my own material. Saying that, I am not sure whether, had I had the option of following the lesson plans exactly as they are, I would have. Main findings:

- All lesson plans can make, in their current state, 1 hour lesson activities in a classroom make up of 10 - 30 children. Split into groups, the lessons are suitable to be approached with children in Year 5 and above, and be completed in time.

- The main factors influencing the ability to complete the lesson plans in 1 hour slots are: the available adult support, the time it takes to setup SAM given that often in Windows environments technical issues occur, the complexity of the lesson and the children's willingness to follow the steps of the lesson plans more or less as proposed. Some groups may complete the proposed activity in the given 1 hour slot, whilst others may not. A lot of these factors are outside SAM's control, but in a normal classroom, even with 30 students, provided there is a suitable amount of discipline and no major technical issues, all lesson plans can be followed by a single teacher with a majority of groups completing the activities.

- The lessons can, in their majority, be approached with children of any age in Year 5 and above - the lessons do not lose their relevance with the children's' age - the main factor is the students' previous experience with SAM rather than their age.

- The lessons are great 'starting with SAM' activities, however for students who have already worked with SAM for over one year, they are too simplistic. The Keble students, who in their majority had already worked with SAM for over a year, found the lesson plans as they were too simple and new, more challenging activities had to be planned.

- The lessons plans were the main inspiration behind every lesson - whilst they might have not been followed exactly as they are, they were the main source of ideas and behaviours presented. 6 out of 20, the total number of code clubs across all schools were help following the lesson plans exactly as they were - 'As per the lesson plan'. This is important - having a main source of inspiration for ideas and possible activities is critical to the success of SAM in the classroom. When asked, even for the most seasoned users such as Keble (and in fact, especially for them), all teachers unanimously reported the need for ideas - many ideas - to get inspired from. A constant source of feedback from teachers is that, even if they understand the tool and feel it holds great potential, they struggle to think of many lessons ideas they could come up with, and given their lack of time, it would be extremely hard for them to use SAM consistently without a big pool of potential ideas they can choose from.

- The lessons do not build on each other. Especially because not all students complete the activities in one hour depending on the challenges which occur from lesson to lesson, moving to a completely different activity the next hour is potentially detrimental. In addition, there is little building on previous knowledge given the separation between the different lessons' aims. Whilst the variety of ideas is great in terms of offering inspiration for teachers, it is not helpful when building a sequence of lessons which consolidate certain concepts the teachers are aiming for. Ideas which were incorporated in the code clubs delivered in order to support a more progressive path towards SAM concepts were: if new blocks were introduced, the activity aims remained similar (eg: alarm systems with different sensors from one lesson to another); introducing new ways of using the same blocks (eg: the same car equipment was used throughout four different lessons, building on the behaviour from the previous one); associations between lessons using the inputs -> connections -> outputs structure to consolidate the higher-order logical thinking.

- Content creation - it is the construction of the lesson plans which took, by far, the most amount of time and effort conducting the code clubs. Thinking of appropriate ideas, which build on each other, which are suited for the environment, and which I am confident in delivering was intense and difficult. Whilst I am not personally a teacher, this does correlate to the teachers' reported main challenge - finding the time to source the ideas and apply them into the classroom. It is, in fact, one of the biggest challenges still recognised by the wider computing community - what is best to teach, using what tools, what content and in what sequence, following what structure? This content challenge is by far the biggest SAM is facing entering the classroom - given that there is are still little concrete examples of how best to tackle the computing curriculum, identifying a sensible approach is by no means a task for SAM alone, but faced by the industry as a whole. In comparison, tools like Scratch and Raspberry Pi have allowed the community to take the lead in terms of how to best use them - whilst currently there are almost unlimited resources around what can be done with Scratch or Raspberry Pi, these have mainly been brought about by the community itself - the users who found the tools useful and figured out ways of using them.

- On average, it would take me around 1-2 hours to finalise a lesson plan. This is also what Karen reported when asked how long she spends on planning her own code clubs.

- On average, I would say that 60% of the content in the lesson plans overall made it into the code clubs, including the inspiration ideas they provided, whereas 40% was made up from scratch. When asked, teachers reported that they usually edit lesson plans which they find online for other tools, on average, by 20 - 30%, however of course this is a very relative average which may depend entirely on the available resources, etc.

<u>Type of approaches of the lesson plans</u>
3 types of exercises and ways of introducing SAM new ideas, depending on he childrens' SAM expertise:

- Lesson plan - structured, following a step by step structure - great for introducing the general concept and introducing new blocks and how they work
- Variations of the same blocks - using similar blocks as previous lessons, find new ways of applying them to different contexts - with no increased complexity or any added new blocks / knowledge, simply make variations of the same stuff - allow the children the time to rehearse, practice, consolidate on previously acquired ideas
- Invent something within set boundaries - using these two blocks, or aiming for this behaviour, set something up - great for putting the same knowledge into different contexts
- Fix a broken project - the whole system is there, but it has faults - find specific issues within a project to solve in whichever way the child sees appropriate

- Look at this graph and tell me what it does, then extend it - worked example - great to provide more inspiration of further contexts they haven't thought of but in a more complex setup

- Often the content in the lesson plans is too dry and the language too complex - there are links to real world applications for the main lesson activity, but this doesn't usually permeate to the smaller steps - the on/off block, the logic gates - these are simply introduced as necessary steps to achieve the greater goal, rather than warranting their own introduction and understanding. Words that are not child-friendly are sometimes used, which confuse the lesson.
- There is little scope for student interaction - whilst at every step of the lesson, questions are proposed, they all lead to specific answers, and valid answers have to be discarded simply because they do not follow the structure / steps of the lesson plan. So whilst the questions allow for the students to think for themselves and make their input, unless these inputs follow the lesson structure, they are deemed as irrelevant, which becomes frustrating and confusing.

- ## Can the activities be understood and finalised in a one-hour lesson without significant pre-lesson prerequisites or post-lesson extensions for the students?

- No prerequisites or homework was ever assigned to students during the code clubs. Whatever happened during the one hour lessons was the full extent of the students' participation.

- Given that this was one of the lesson plan aims, to be able to be followed in 1-hour sessions, such prerequisites or homework wasn't even considered. Saying that, there were not times where I felt this would be necessary. Perhaps given the nature of the tool - physical blocks which I took to the schools - it wasn't an obvious questions, but it felt like the activities in the lessons were suitable for the 1 hour slots.

- Not all students completed the activities in the 1 hour lessons - as per the table of lessons above, at times only half of the class would complete the activities. However all students consistently made good progress, reaching the final stages of the activity. During the reflection section, the students who hadn't completed would see a final version of the project which would often clarify gaps. Given that the lessons were, as much as possible, constructed to build on each other, students would get the chance in the following lesson to complete the previous graph.

- Can the lessons plans be followed as they are without additional clarifications or modifications and with minimal pre-class preparation from teachers?

One of the aims of the lesson plans was for the lessons to stand, individually, as one hour activities, to be approached by any teacher, regardless of their SAM expertise, and potentially with no time to prepare before the classroom, and deliver the lesson successfully. Main findings:

- It would be very difficult for teachers to pick up the existing SAM lessons and for them to be delivered with absolutely no preparation at all by the teacher ahead of the lesson. Several reasons:
    - The teachers do not feel comfortable going into the lesson unprepared
    - The teachers have different approaches, and usually change the lessons based on their own style as well as the bespoke needs of the different classes they are teaching - all teachers reported they very rarely stick to exactly the same lessons year after year, given that the children in their classes are different year-after-year, which demands a dynamic adaptation of the lessons
    - The teachers ideally do want lesson plans they can simply follow, with no modification, especially given the lack of time on their hands day-to-day to prepare extensively. However they recognise the problems in obtaining that - they take different unique approaches tailors to their styles and their students, and they actually want to take the time to feel confident and prepared when walking into the classroom.

This brings an interesting challenge to the SAM team - do they focus their efforts on making the lesson plans perfect to be followed by new teachers with no previous computing training or preparation, or do they make the lesson plans the perfect skeleton for teachers to take and adapt, concentrating on minimising the effort the teachers have to put in adapting the lessons. These are critically very different goals, which lead to different types of lesson plans, with different features.

- The lessons are not easy to follow unless you know the content well and you have prepared in advance. They are lengthy, and it is not clearly signposted what information is critical, what information is explanatory and can be skipped depending on the context, and what information is additional extra. As a teacher, if you were to follow one of the lessons without having seen it before, you would waste a lot of the lesson reading through the plan yourself, identifying what should be shared with the students and what shouldn't. They lack an overall, clear and simple structure which stands out and can be understood as the teacher progresses through the activity with the children. (Note: the current version of the SAM lesson plans is a SIGNIFICANT improvement towards the issues stated above, in the right direction, in comparison to the initial version of the SAM lesson plans made available to teachers. However, there is still room for improvement in the same direction)

- The planning of the bespoke lessons, inspired by the existing lessons plans, with the added aims of building on concepts lesson after lessons, providing a sensible sequence of increased knowledge, moulding the lessons to the children's' attitudes and SAM expertise, resulted in new variations of the lessons plans being created. These were not written down as explicitly as the current ones, but were mainly a skeleton following the structure presented earlier in this report.

- The current lesson plans do not easily cater for alternative solutions. Whilst the plans mention 'possible solutions' as sample results, they do not offer alternatives which can spark new ideas / new approaches. This is critical in computational environments where one of the basic ideas is that the same goal can be reached through various aims, and can also cater for different types of thinking.

- Most of the code clubs were prepared in advance, with a concrete idea of the activity and the main steps to cover, in order to cater for the changes happening in the classroom. Very importantly, no matter the extent and time spent preparing the lesson, it never materialises in the ways expected - teachers confirmed this as a day-to-day reality of the classrooms. However the pre-planning ensured that teachers are better prepared to deal with those variations, and indeed it helped me as well. The lessons never followed quite the prepared plan, with changes to the sequence of steps followed, to the ultimate goals - sometimes children would get excited about al alternative way of reaching the same result in which case it proved significantly more beneficial following the students' flow rather than getting them back on the lesson plan path.

• Is the content of the lesson plans relevant to the curriculum and appealing for teachers?

As far as witnessed, the teachers were positive about the link between SAM and the curriculum. Whilst they all agreed that a whole term would need to be better structured around the existing lesson plans and new lessons introduced, they felt that the activities could match different parts of the curriculum. In addition, they felt that with more ideas, they could introduce SAM across the curriculum into a significant part of STEAM lessons. However teachers felt that the amount of content needed before a school could use SAM extensively would be very significant. To put it in perspective, tools such as Scratch and Raspberry Pi have hundreds of ideas and lesson plans published online, with teachers still struggling to fit them exactly to the way they want to cover the content in their own schools.

• Do the students enjoy and engage in the activities set out in the lesson plans?

Yes. See the "Engagement" section earlier in this report.

Educational Impact

The code clubs were not designed as experiments targeted towards a better understanding of the educational impact the SAM Kits have on the children. The lesson plans were tested around their feasibility, rather than effectiveness against learning goals. The effectiveness of SAM as an educational tool is a much more complex area, dependent on a variety of factors. However some observations can be made towards the educational impact the code clubs made on the children present. Main findings:

- The children clearly associated the SAM kits with robotics, programming, and computing concepts. Depending on their additional computing experience (some of the children had used Scratch and the children at Keble had used a variety of computational tools - virtual as well as physical), the children made clear links between previous learnings and the SAM tasks, such as sequences of steps (blocks in a circuit in a precise order) or triggers activating certain behaviours.

- Most of the ideas and concepts used in SAM appeared new - Internet of Things, physical computing blocks paired via bluetooth, sensors, circuits which need to be assembled in order to create full systems. Whilst some of these ideas, at their base, overlap with other computing tools such as Scratch, the children did not associate these directly.

- Whilst no tests were conducted in order to verify the children's' specific understanding of SAM, given their ability to work with SAM by the end of the semester verified that the children did understand the basics of the tool and how it could be used. All children were able to setup SAM and create basic connections between physical inputs and outputs. A majority of children (80-90%) knew how to use basic software blocks in the connections to manipulate the output: filters, hold, interval, counter. A minority of children (20-30%) got to display a full understanding of the majority of the content covered in the lesson, and a confidence in explaining how they put their solutions together.

- The children's' preferred way of using the blocks was finding ways in which they could use them for their own personal self-made goals: creating a disco-ball, adding sound effects to their cars, thinking of ways of integrating their favourite blocks (motors) to the task in hand (smart house) eg: we were thinking of adding a motor which could go to the neighbours and alert them that the house was burgled.

- It was difficult, at times, to have the confidence that the children can be left to figure something out on their own, without explicit prompting or step by step guidance. However given the high engagement levels the code clubs brought, it would often be enough to set a task which was in the children's appropriate level of complexity, and the students would, in the majority of times, find ways of completing it.

- The students struggled to think logically, in terms of inputs -> connections -> outputs. They would often just dump the blocks onto the working canvas, anywhere, in no logical layout, and start making connections. The input -> connections -> outputs idea had to be reiterated again and again in order for students to start following it. They would often struggle to identify whether a button would be an input or an output (alternative words and ways of phrasing the questions were used: triggers and results, start and end, etc.) however it was a conceptual rather than language problem. I believe that, in the same way the example graphs in the lesson plans have been structured following an input -> connections -> outputs framework, the canvas interface in the SAM app would benefit from the same separation, to force children into separating their blocks in this logical sequence.

- The children would find it difficult to find a suitable sequence of connections between the available blocks once the workspace had more than 3-4 blocks on it. Because of the random positioning on the open canvas (the buttons would be place in the bottom right, the lights in the middle, the filters in the middle top, etc.), the children would find it difficult to figure out what needs to be connected to what, past the obvious 2-block connection. In order to get something working, the children would often connect everything to everything until they got something working.

- Children had different approaches to the projects
    - The beginner children (Elizabeth's and Mowlem) would use as many blocks as possible, making their graphs incredibly complex, very difficult to untangle and understand, but since everything was connected to everything, something did happen.
    - In order to fix a problem, the answer would most regularly be adding something - another block, another connection, rather than removing. Whatever was there in the graph was seen as necessary and adding seemed like the obvious solution to fixing any problem, even if they didn't fully understand how the newly added blocks worked.
    - Testing wasn't something they would undertake as they built to verify each step - they would mostly complete the graph as they saw fit, and at the end, test to check for the outcome. Often, a result, any result, would be good for them - as long as it was roughly similar to the desired outcome.
    - The more advanced children (Keble) would try and take it step by step, to understand the purpose of every block and know the appropriate way in which it should be used in the graph. However an increasing number of students at the other two schools also evolved towards such an approach - proof that to some extent, the children increasingly adopted 'problem-solving' skills.
    - The testing at Keble would be a lot more precise - it still wouldn't really happen until the end of the graph, but the children would be looking for much more accuracy.

The children also really enjoyed helping each other. Whilst they would ask for my help with logistical problems (the blocks won't turn on, the blocks won't pair, etc.), - problems they felt they really couldn't solve amongst themselves - they usually asked each other for help around solving the actual SAM tasks - the problems that clearly were set for them, with the expectation that they would be able to solve them on their own.
Most students would attempt the tasks set by the lesson plan, within their groups, and on failure they would either:

1) Seek help or inspiration from other groups - especially if those who would loudly advertise their success. Equally, once successful, students from the groups which succeeded would often proactively go to other groups and try to help.
2) Seek my help - Often, if the student had reached the point where they would ask for my help directly, they would have the expectation I would solve the task for them. Rather than trying to understand where they might have gone wrong, them being stuck meant an adult was due to come in and fix the situation for them.
3) Move on to using SAM in a different way, make up their own approach or build an entirely different graph altogether (eg: building a disco ball when the main lesson consisted of building an alarm system)

The different coping mechanisms when children encountered failure were different amongst children, as well as from situation to situation. There appeared to be invisible thresholds of difficulty level for each student which would lead to one of the three possible actions above, depending on the situation at that given point in time.

Overall, the SAM code clubs were a valuable experience, both in terms of observing SAM usage 'in-the-wild' as well as for a better understanding of the lesson plans requirements. Not having a very specific short-term experimental agenda allowed for a useful observation of the potential SAM has in the classroom and its current challenges.

Appendix K

Iterative Design Journeys Complete Student Cohort

Iterative Design Student Journeys – Complete Set

Student K

Student K struggles to identify a board game he wants to implement in the first lesson. He considers a few different ideas, a five-second rule game, or a question-and-answer card game, but is hesitant about starting to work on prototypes. He is also reluctant to upload his sketches to SeeSaw: "I don't think the initial drawings are very good. Can I just write a note about what I'm thinking?". When the teaching assistant asks about his progress, Student K tries to ignore him: "What are you up to atm?" <no answer> "So what are you actually doing?" Student K mostly mumbles and avoids an answer.

The teacher notices his initial lack of engagement, and comments at the end of the class: "One thing I wasn't happy with was his attitude. He seemed to lack focus and enthusiasm."

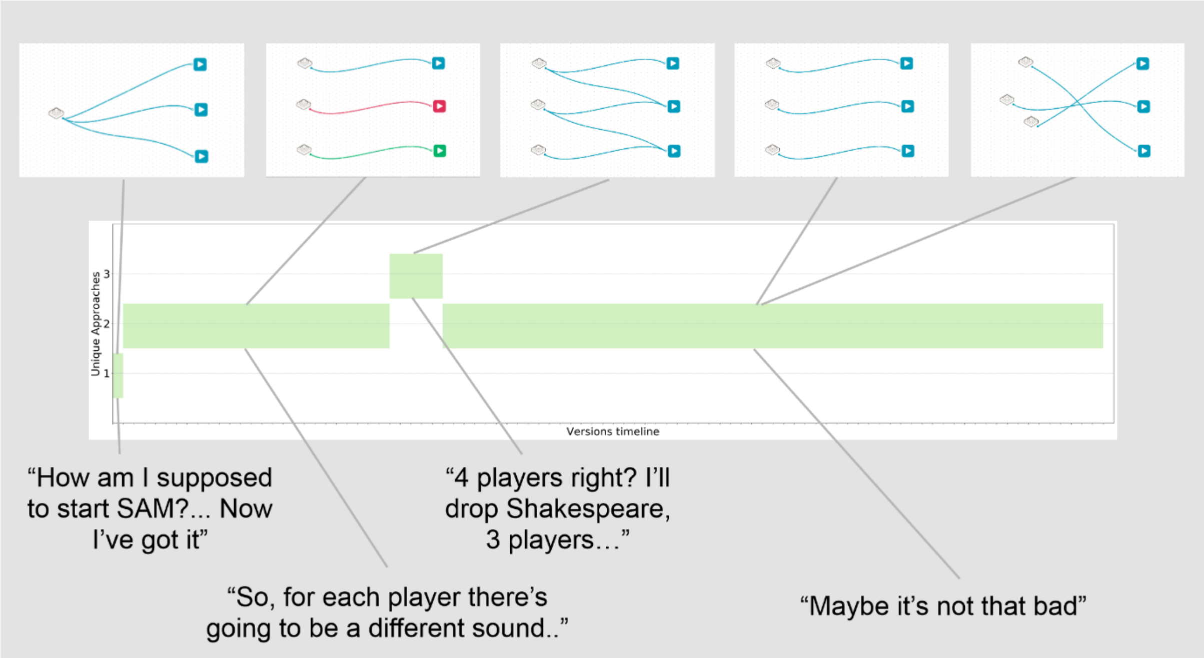
By the third lesson, Student K changes the game plan altogether, deciding to implement a snakes and ladders board game instead. However, he adapts the snakes and ladder game to include questions the players would have to answer when landing on specific places on the board, with a five-second time limit. This is the first iteration Student K makes to his overall game plan.

Question Buzzer

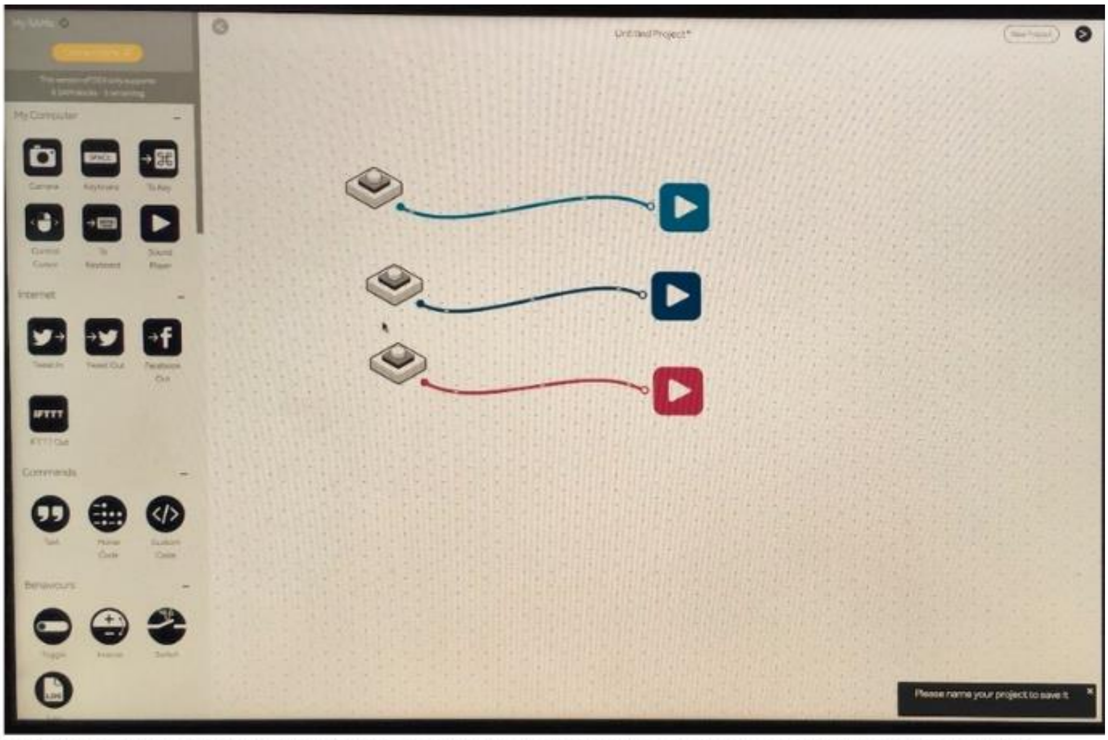
Once Student K decides on the snakes and ladders game to implement, he turns to SAM Labs and considers starting to build a buzzer for the players to use when answering the game questions: "OK fine, I'll start with SAM". The start of building with SAM Labs leaves Student K stuck: "How am I supposed to start SAM?", "So what blocks do we need to use?"

He starts picking up different SAM Labs blocks and turning them on and off: "OK… so what is this?", "OMG this is a light sensor. OK ..how do I get rid of it..?". He looks around the classroom at what his peers are building looking for inspiration: "Lachlan, lachlan, lachlan what am I supposed to do with this SAM?!? I need some help with SAM", "I have no idea" and slowly starts to get unstuck: "I'm not stupid. How do I do it? I am becoming stupid, I am becoming stupid, how do I do it?", and turns on the player using a button: "Now I've got it".

The 'Approaches over Time' visualisation captures Student K's iterations of the question buzzer, with quotes from Student K's audio matching each approach.

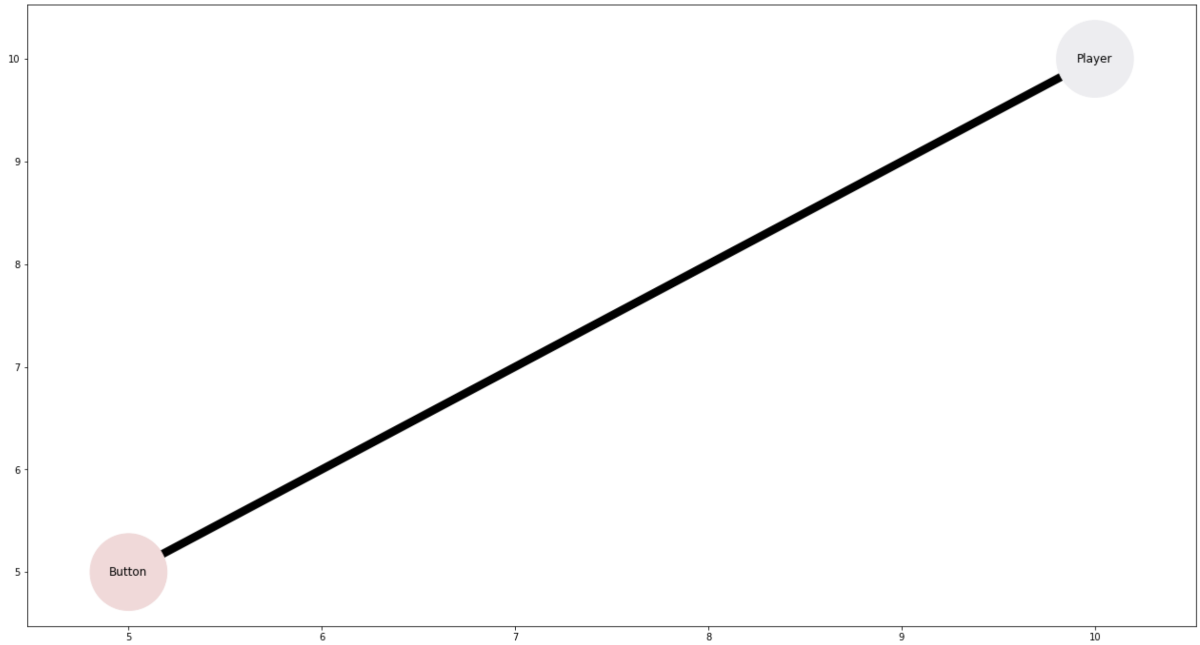


In the first version, he links the same button to three Players, intended for each board game character. In the second version, he realises that a single button cannot serve multiple players, so he gets some help from the teacher explaining his goal: "So, for each player there's going to be a different sound.." Teacher: "OK, go get another button". He also iterates slightly on the game setup, in view of the sounds available in the Player, moving down from four to three players of his game: "Yeah, I'll drop Shakespeare, 3 players…". A third version of the buzzer emerges, but Student K quickly reverts to the three single Button -> Player circuits. For the rest of the lesson, Student K continues to test the design physically, without changing the circuit. At the end of the lesson, he proactively takes a screenshot and uploads it to SeeSaw, explaining his work:

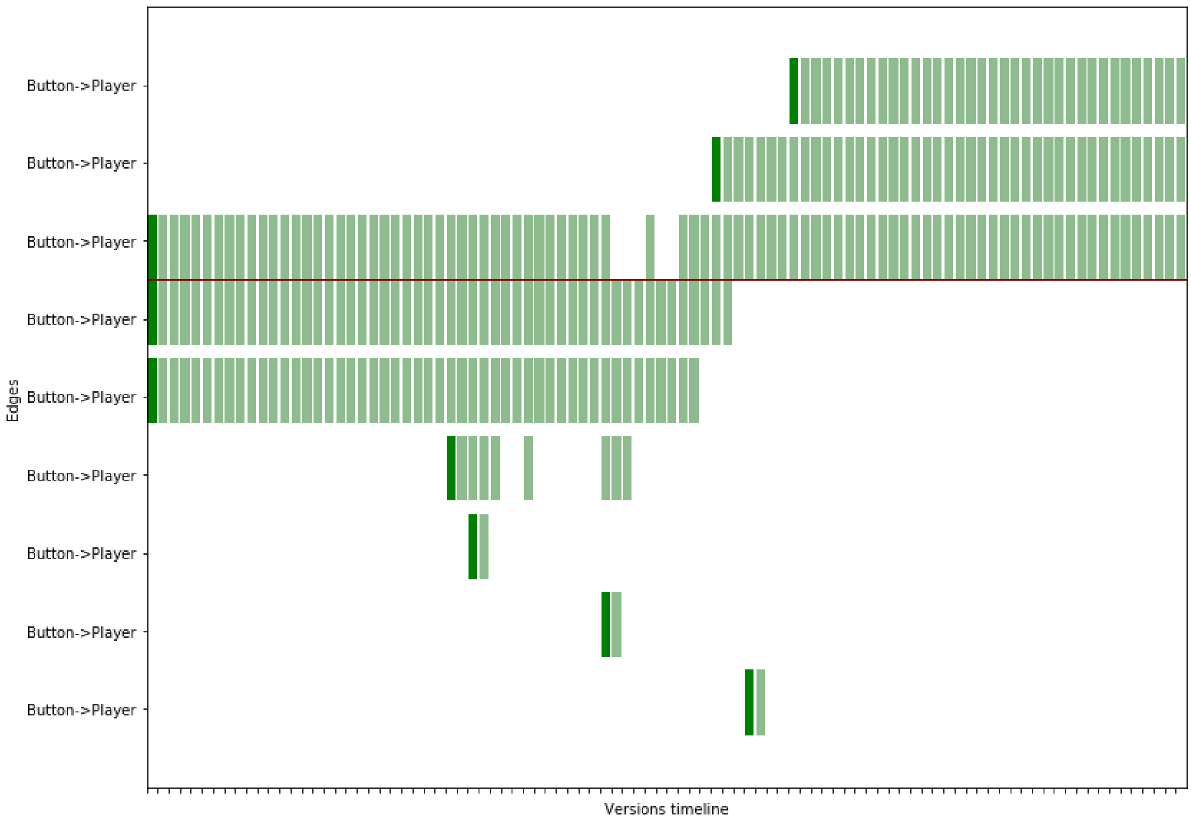


Today I have done my games buzzer fro the three players. The sounds contain screams, plane and music box.

The 'Blocks and Connections' visualisation of the project conveys the only circuit used in the implementation of the Question Buzzer, albeit in a few different configurations.



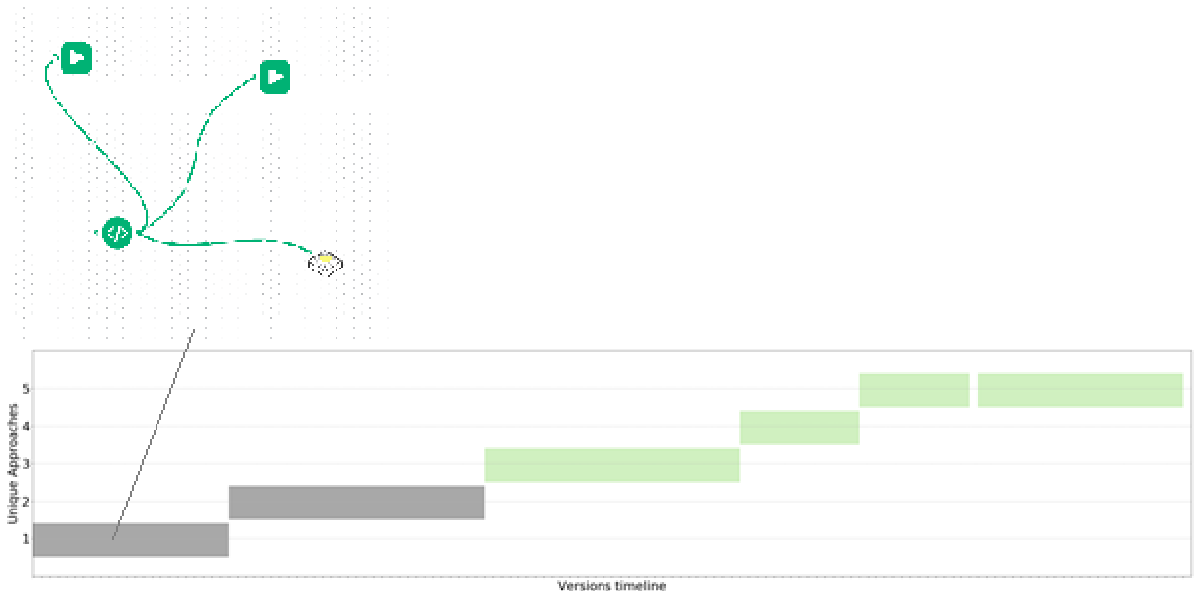
The 'Kept versus Discarded' visualisation shows the Button -> Player circuit used multiple times, with some of its instantiations discarded in the first half of the construction, and two more added in the latte half. This is representative of the different designs attempted by Student K with the same circuit, evolving his idea of how a Question Buzzer might work for his board game.



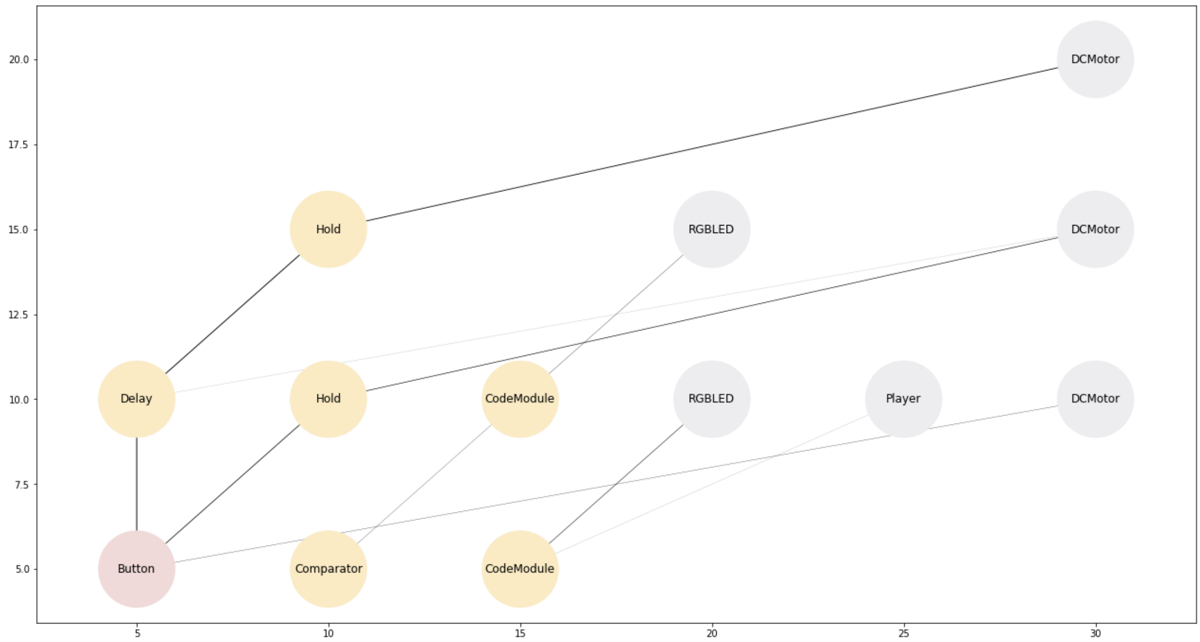
Dice

Emboldened by the construction of the question buzzer, Student K's language around SAM Labs changes from the first lesson of the project. He decides "I'm going to stick to SAM", and starts working on a spinner for his players to use instead of a dice to progress on the board.

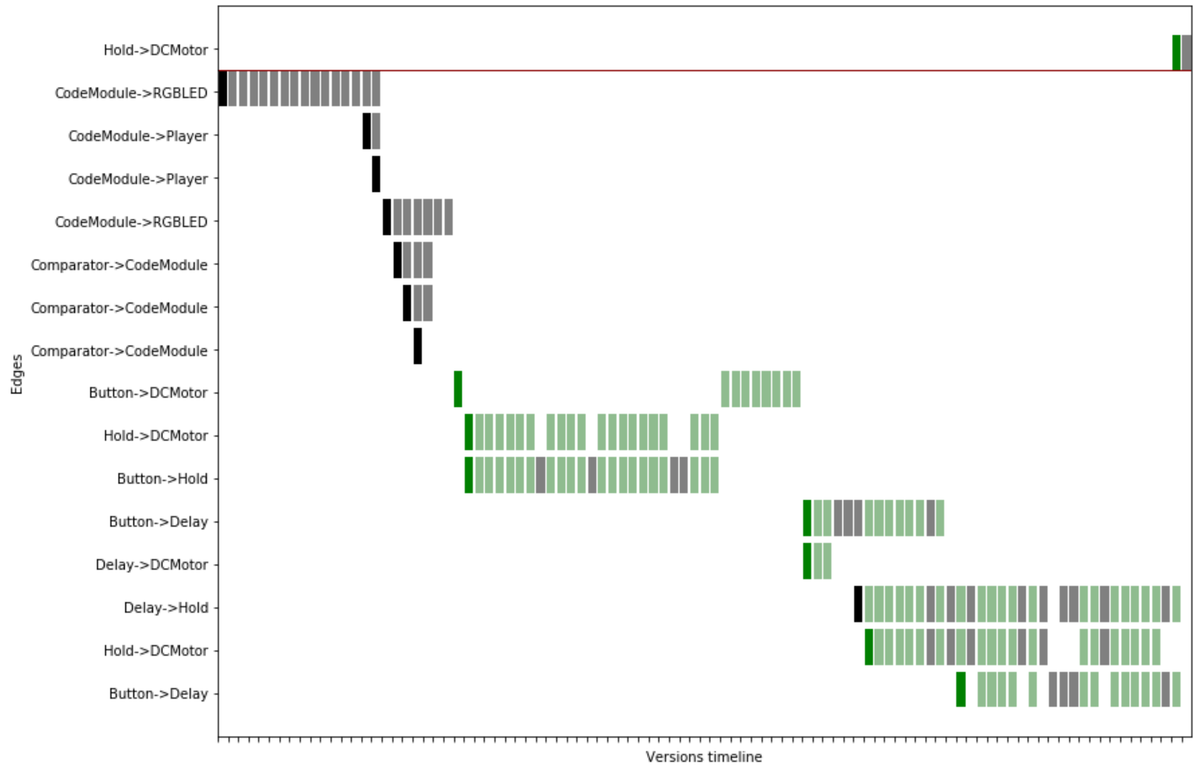
The 'Distinct Approaches' counts five designs that Student K iterates through to arrive at his final Spinner implementation. The interactive version is available at https://6he1j7.axshare.com. The first two versions use the Code Module block, which Student K doesn't know how to use, rendering the versions invalid: "Let's test this, let's test this. That is… no we don't want it like this." As a result, Student K scales back his design to a simple Button -> DC Motor. His next iterations involved randomising the timings of the DCMotor's movements, to avoid players being able to control the resulting number the Spinner lands on, therefore controlling how many spaces they move forward on the board. The last three iterations are valid, and within Student K's comfort zone: "Oh wait, OMG this is going to be the best randomiser… I'm going to put a delay in it".

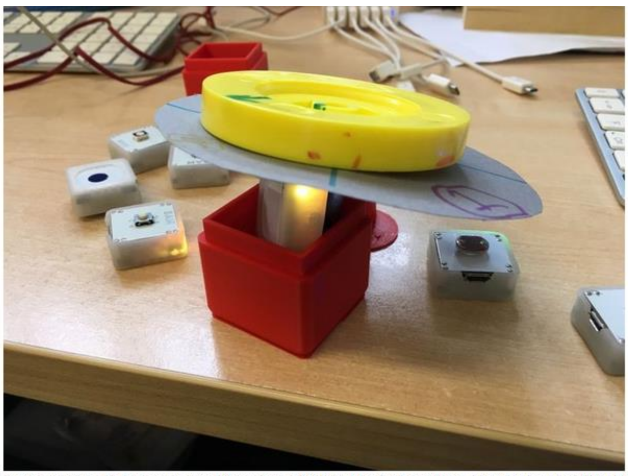


The ‘Blocks and Connections’ visualisation displays Student K’s attempts of using the CodeModule, as well as the different configurations of implementing the spinner using the Button and DCMotor. An equal distribution between iterations can be observed, with an equal amount of time spent on the different experiments, also reflected in the ‘Distinct Visualisations’ approach.



The ‘Kept versus Discarded’ visualisations shows that most of the design work was discarded before arriving at the final version of the Spinner. In addition, it shows the invalid circuits Student K started to build using the Code Module, before switching approaches with increased validity.



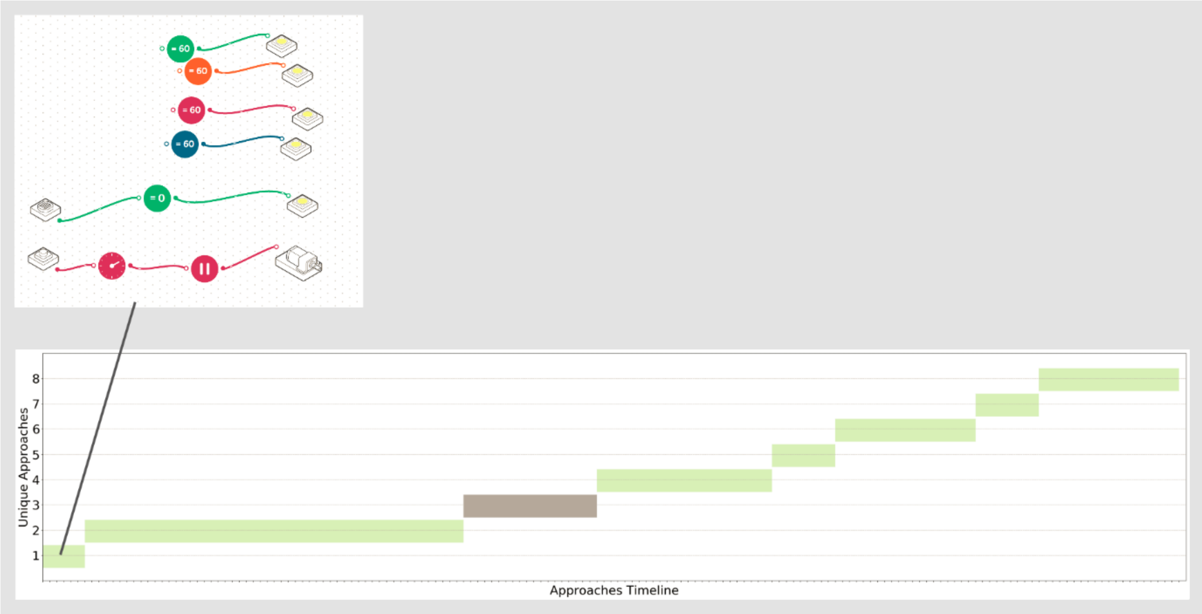


This is the spinner. The box was too small for the whole spinner so we would have to print it bigger for next time. Also the head of King Henry fell off so we have to reprint it as well. The severed head of King Henry 8.

Light Effect

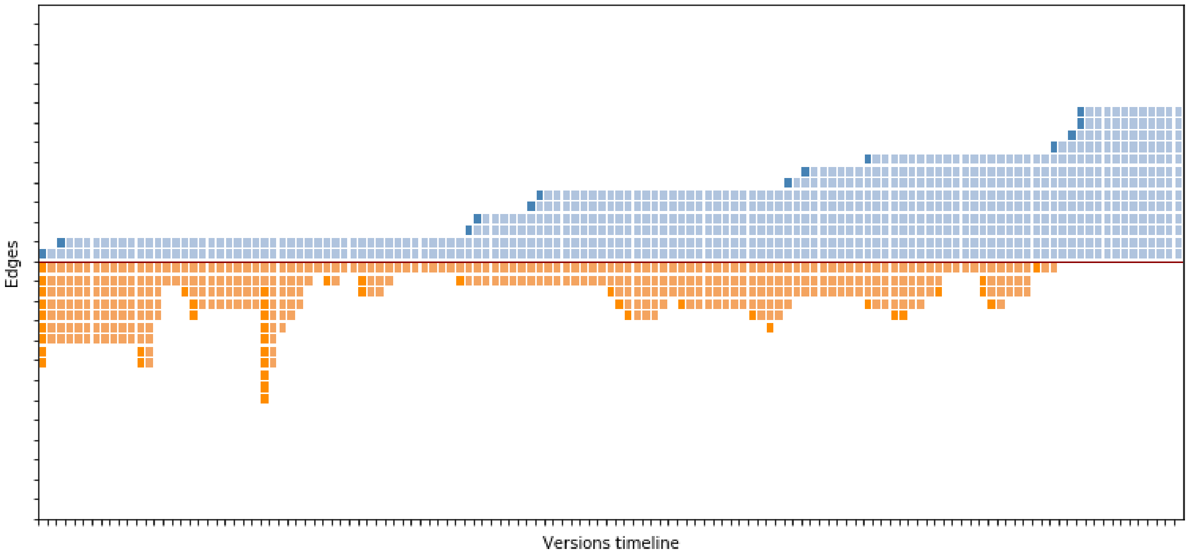
Student K implements a third SAM Labs component for his board game, namely a Light Effect. He starts with investigating the use of the Light Sensor "I can have a light sensor, and when it's 0, just like SAM…", and builds on its functionality to formulate a goal for his board game that fits in with the teacher's guidance to think of ways in which players move around the board: "Yeah, and with a light sensor, you land on it, and you get asked questions".

The 'Approaches over time' visualisation shows eight different designs iterated through to build his Light Effect.

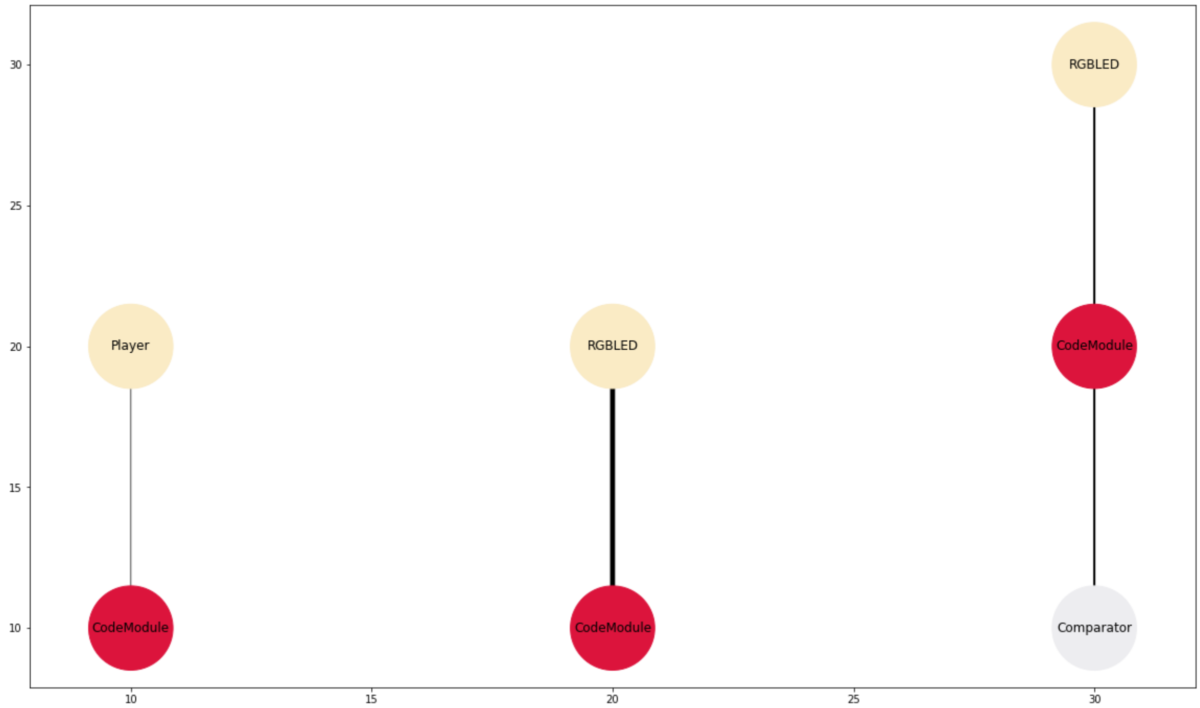


Student K starts in an upbeat mood, singling to himself: "I'm going to do SAMs…" with a Light Sensor which when getting no light in (Compare = 0), it turns on the RGB light. In the second version, Student K changes the Compare block to a Filter, to allow for a range a values accommodating for low lighting rather than no light at all, and uses a Toggle to better control the lights turning on and off. He shows off his construction to his friend: "I've done it! I've done it! Let me show you", but whilst the second design is valid, it's not working as Student K would like it to: "It's not working", "Well, it kind of is but…". In the third design Student K simplifies the circuit back to only one light and changes the input from a Light Sensor to a Pressure Sensor, a move potentially driven by the fact that all other students in the class decide to use Pressure Sensors for their board effects. In the process, he also thinks through exactly the role of the Light Effect for the board game, which isn't fully formulated: "If [..] green, you [..] move forward. If [..] red, [..] go backwards." "Blue?" "Not sure". Using the Pressure Sensor, he builds his circuit back up to three lights, including a Code Module block with help from his classmate. However, because he didn't build the circuit himself, he struggles to get the design his classmate built for him to work: "I can't get it to work..". He switches the Pressure Sensor with a Button to debug more easily, and adds in a Color block to better change the RGB colors. He realises that when the color is dictated by the Color block rather than the RBLED itself, he consolidates the circuit to using a single RGBLED, and finally, switches back to the pressure sensor which he started with to arrive at a final design of the Light Effect.

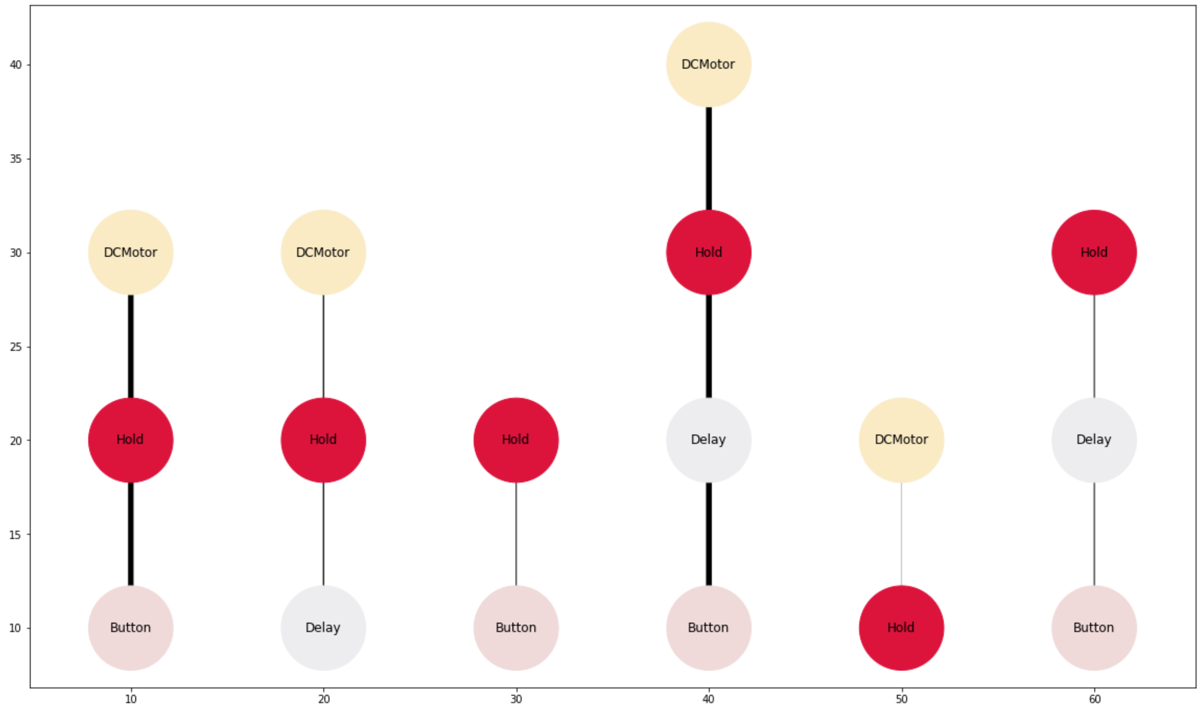
The 'Kept versus Discarded' visualisation displays a gradual build-up of the number of edges in his final design, and a relatively equal amount of discarded adaptations. Given the low amount of discarded work, and the fact that the circuit in the final design is the most used across the project can be attributed to the fact that he had his colleague helping him build the main configuration of the Light Effect, with Student K only making small adjustments.

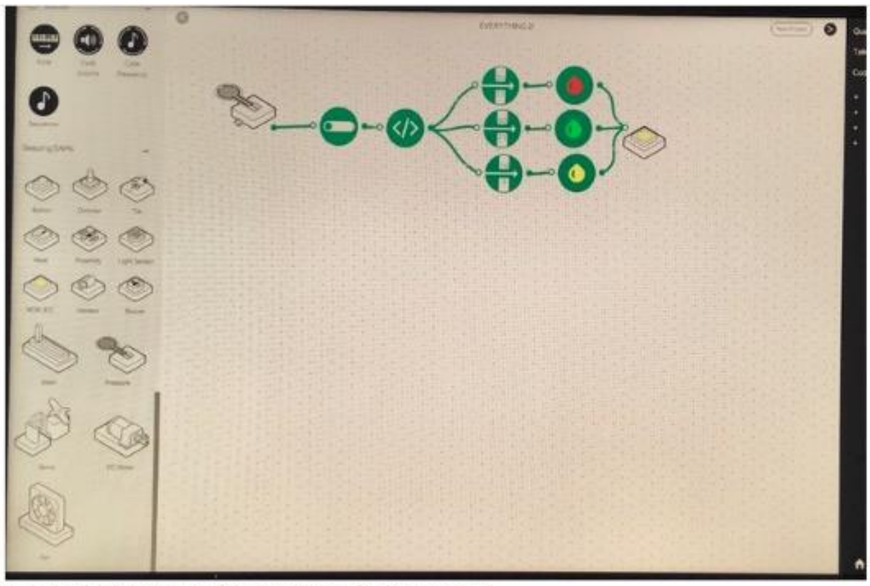


In addition, a query into Student K's use of the CodeModule using the 'Blocks across Contexts' visualisations zooms into the three circuits the student attempted with the block, before discarding his attempts to make it work. All the circuits lack an input block, showing that Student K didn't take his debugging of the Code Module very far. This can potentially be attributed to the fact that this was trying to copy someone else's design, rather than building his own.



In contrast, the use of the Hold block using the same visualisations displays six different circuit configurations, four of which are valid, which Student K tested in order to arrive at a final design.



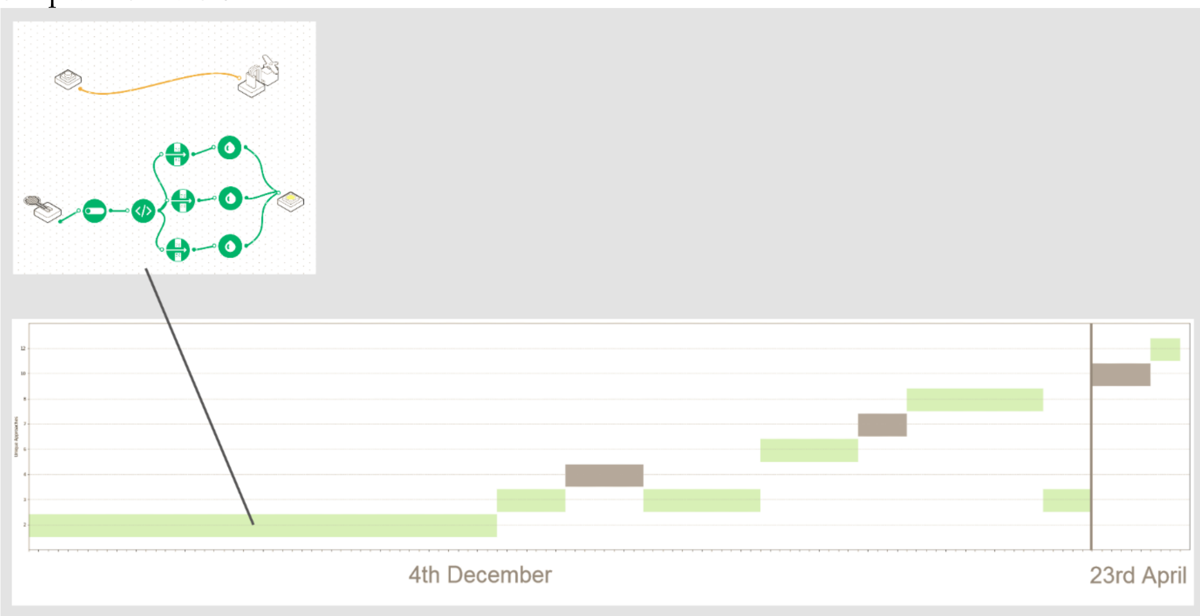


This is the rest of the pressure pad. We had some help from Arthur for the command.

This is the light sensor with the player piece in the sensor.

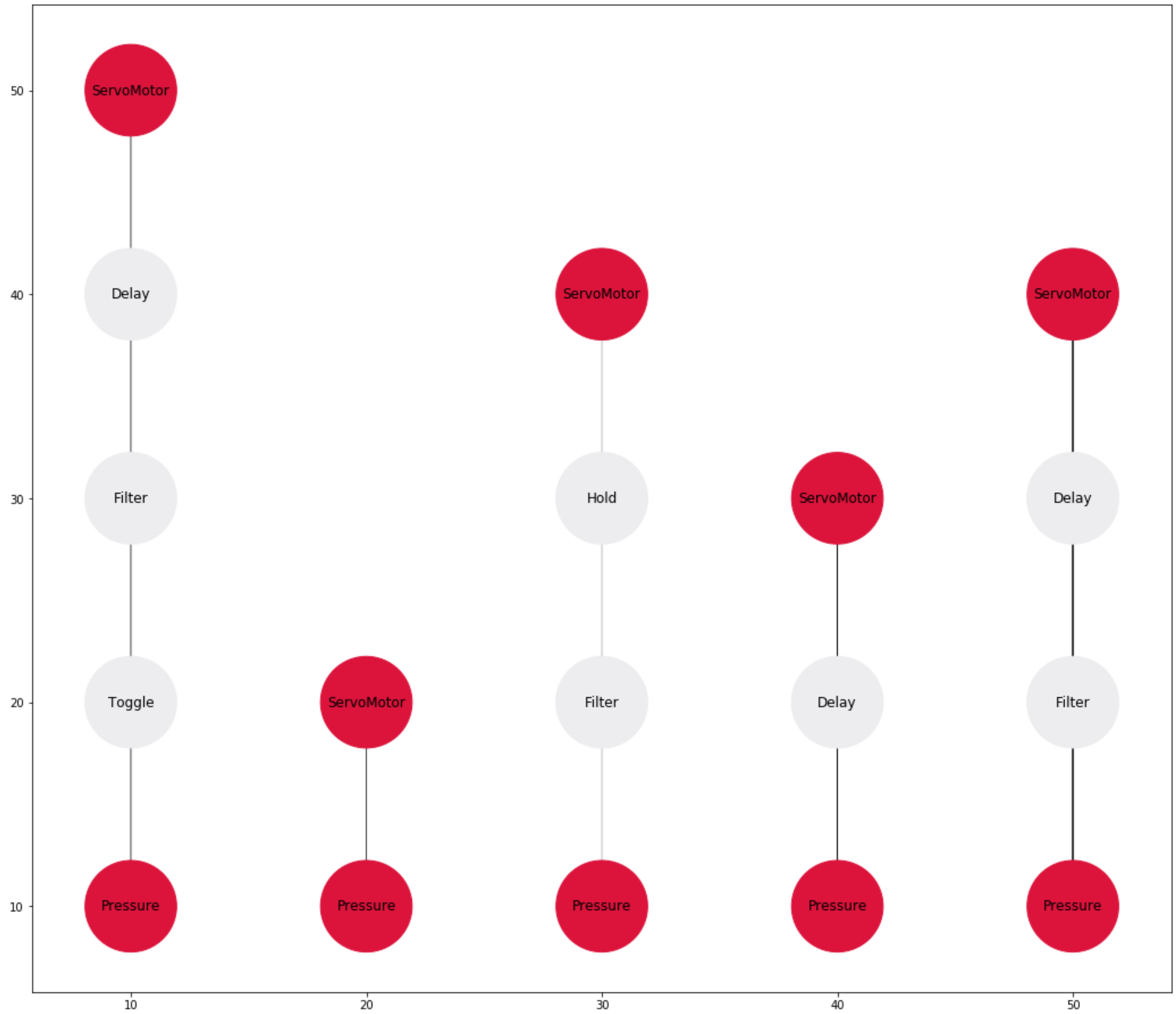
Trapdoor

Student K adds a final SAM Labs component to his board game: "I need something extra... I could do it there, so that when they reach this point they might be knocked out..but how do I put it on the board, like physically?". In a similar fashion to the light effect, he starts building the SAM Labs circuit, leaving it till later to figure out the exact board game use. He starts simple, by connecting it to a button to check the Servo Motor movement, making a simple first version:

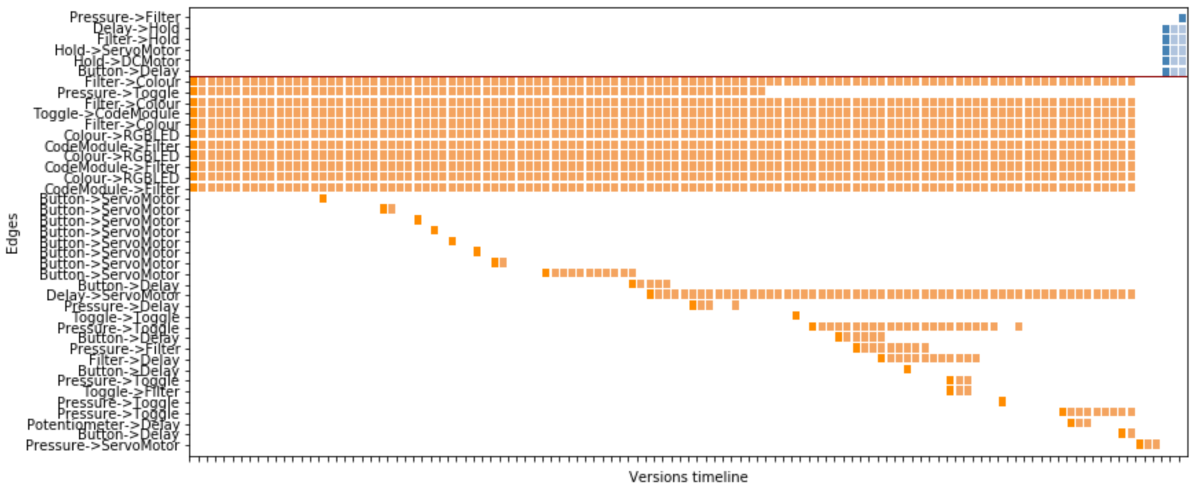


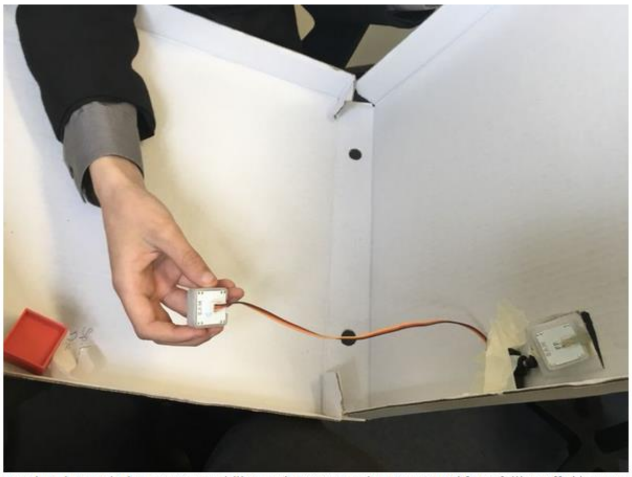
Once the basic motor movement is achieved, Student K starts to refine the exact way in which the ServoMotor moves. He tries a Delay, a Pressure Pad with a Filter and Toggle as used previously for the light effect and several other versions in an attempt to refine the timings of the trapdoor trigger. Student K goes through the iterations without voicing any thoughts. The final version of the trapdoor uses a Button as a trigger, is delayed by two seconds before moving and it holds the movement for several seconds to have time to come all the way down on the player's piece.

The versions mainly switch between two main approaches, one using the Pressure sensor with a Filter, and the other using the Button with a Delay. The 'Circuits across contexts' visualisation displays the different attempts at getting the ServoMotor controlled by the Pressure Sensor. All the circuits would have cause the ServoMotor to move, but they clearly did not satisfy Student K's requirements on the type of movement he was trying to build:



The trapdoor is Student K's final construction, entirely built by him. In comparison to the previous SAM Labs elements, it is the most iterated on, with Student K discarding most of his attempts, to only contribute to his final design in the last part of the lesson, as displayed in the 'Kept versus Discarded' visualisation:





We've added boxes to support the pressure pad underneath the servo to stabilise and prevent and pressure pad from falling off. Also we are planning to moderate the board to fit in the lights we are thinking of putting in the board game.

Conclusion

Student K's initial lack of SAM Activity, and simplicity of the first SAM construction, the question buzzer, is reflective of his hesitancy with which he started the game. The visualisations across the four components display a narrative of increased iterative design work, with Student K trying more, distinct solutions, and becoming more adventurous in his attempts. This was also reflected in his engagement with SeeSaw and the teacher, which was minimal to begin with, and grew steadily across the project. His willingness to engage in the iterative design process increased steadily over the course of the project, growing increasingly comfortable to test new blocks, try our designs he didn't know would work, and embrace a 'testing' attitude: "Let's test this, let's test this."

On several occasions his goals got adapted in view of what he built in SAM Labs: using three players instead of one to have different sounds for his question buzzer, the exact game instruction depending on what colour the Light Effect emits, or the type of movement for his Trapdoor.

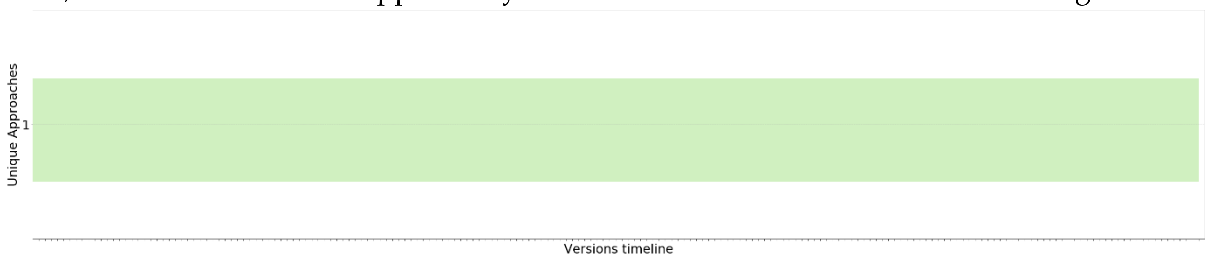
Student N

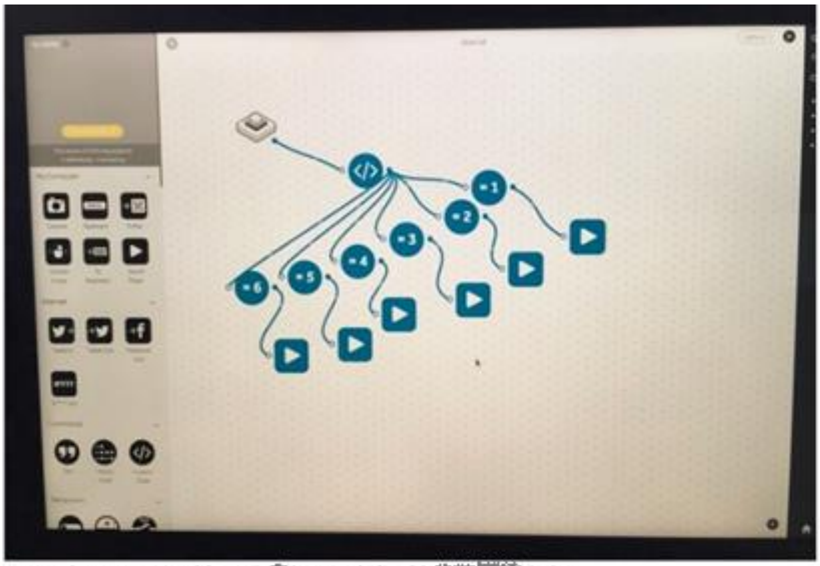
Student N has a clear ideas of what board game he will implement "My game is Wives and Ladders", a take on Snakes and Ladders with the required history spin on it, but is unsure about his SAM Labs implementation: "I don't know how we'll make the game intelligent. I've got the die roll, once you start. But I can't think of anything else."

Dice

He starts working on a Spinner, one of the ideas from the teacher. He iterates on the solution in his mind before starting prototyping anything: "I'm going to find a way to make a random number, there's going to be a light sensor and it's going to say what the number is". Talking through the solution, he changes the light sensor with a button, and the voice output with lights: "I'm going to do it so that there's a button that you press, and you get to click it twice, and there's red, green and blue, and you get to click it twice to get to 6". However, he is uncertain about how he's actually implemented his Dice: "I'm not sure how to do it so that it's just the button, for it to come up with a number".

The 'Distinct Approaches' visualisations shows that Student N works on a single approach for the entire Dice implementation. From the video recordings it transpires that the teacher helped him achieve the solution, without requiring Student N to engage in any iterations. At the end he is excited to test it "We'll test it out!", pleased with the result: "Yes!! This is the best!!", "This is the most complicated SAM I've ever done….". He proactively takes a photo and uploads it to the SeeSaw platform, acknowledging the help he got: "This is [..] SAM random number generator. Me and X made it with Y's help". Despite going through a single iteration, Student N isn't reluctant to engage in implementing something he isn't familiar with, instead excited at the opportunity to learn about the Code Module and testing it out.





This is our SAM random number generator. Me and [redacted] made it with [redacted] help.

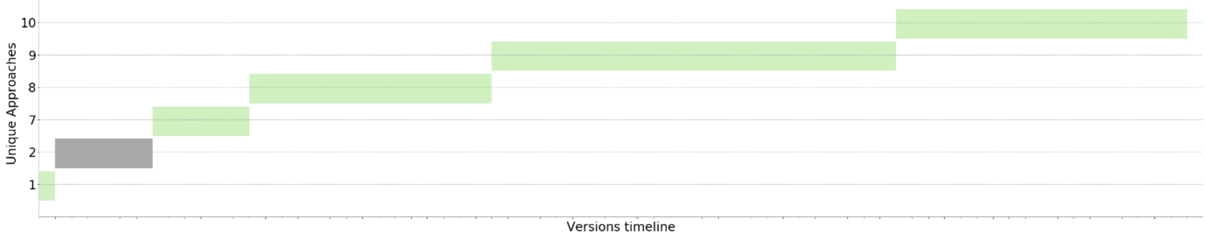
October 16, 2017, 11:47 AM

♥ [redacted]

[redacted] We started with the idea of a number on the screen but we later decided to use our voices to say how many spaces to move

[redacted] We used a website which taught us how to do the java script for the random number

Trapdoor

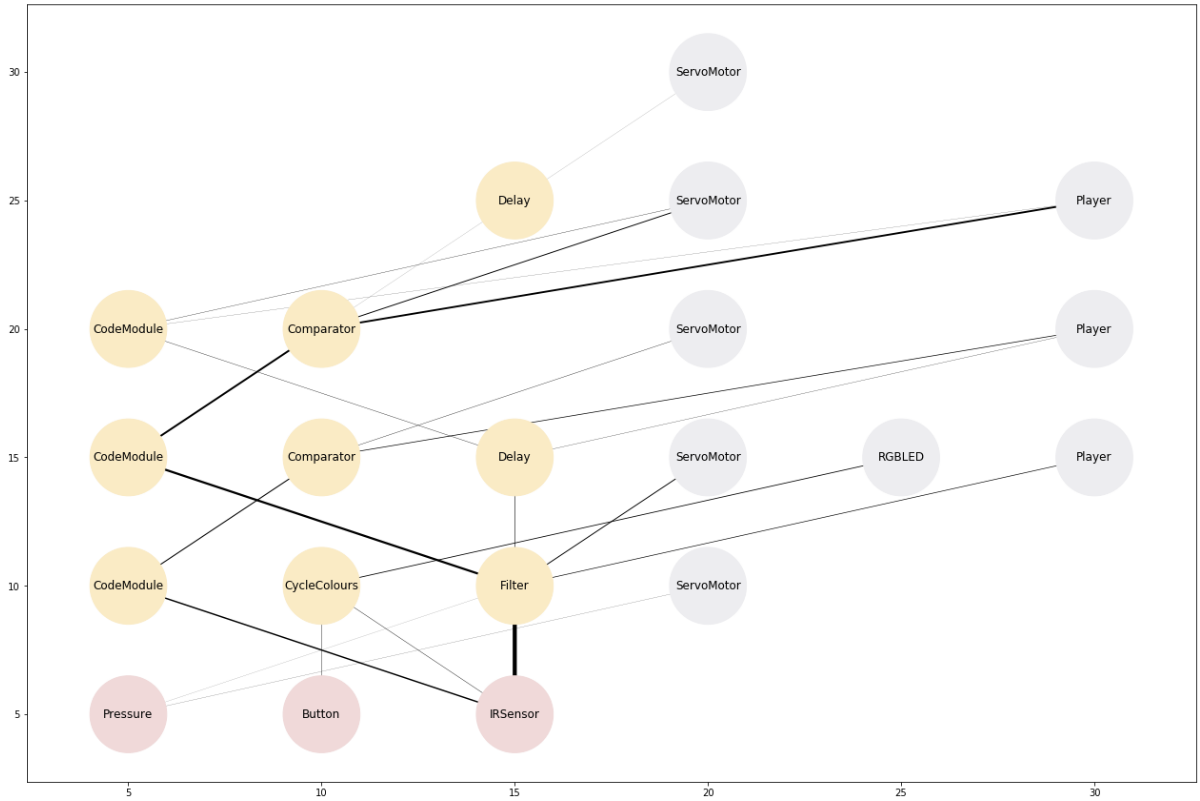


For his trapdoor, Student N starts with a simple trapdoor implementation using a ServoMotor to activate it, and adds in a simple colour effect, initially separated from the trapdoor. However, he is uncertain about how the components fit into his game, constantly checking whether the behaviours are suitable for the project with his teacher: "Would this work?" "It's a random noise for now, but maybe a trumpet noise when you open the box..". The teacher offers reassurance, and Student N continues to refine his implementation over six main iterations. The interactive version of the 'Distinct Approaches' visualisation is available here: https://tmi0sr.axshare.com.

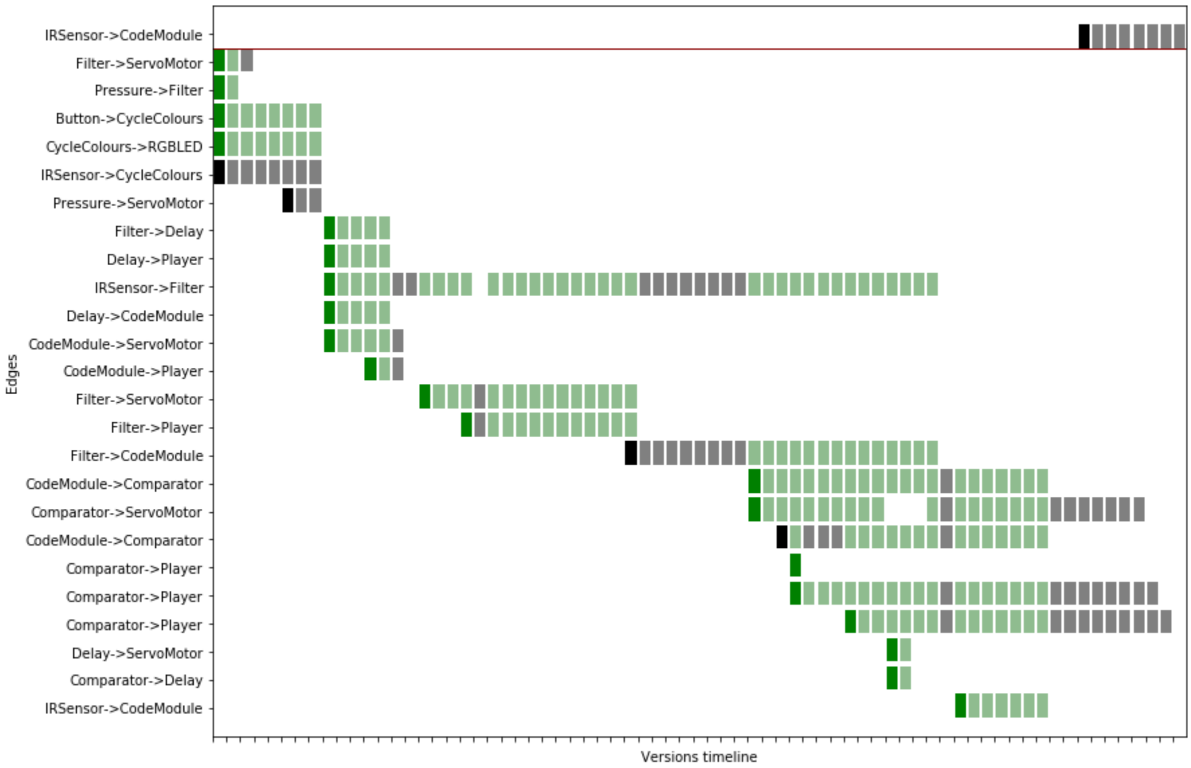
Student N is comfortable with testing different versions of his component, without a precise idea of what he would like the final design to be: "I'm doing a random colour generator. If you land on a block…", "The idea is…I'm testing this". On completing a second design approach, he checks in with his friend the trapdoor's functionality expectations, which gives him the idea of a sound accompanying the servomotor: Student N: "The proximity sensor works with the servo motor. What do you expect to happen exactly?" Friend: "It will say 'you are dead!'" Student N: "I can have a scream!". This results in Student N merging the sound effect component with the trapdoor, resulting in a circuit which uses a Proximity

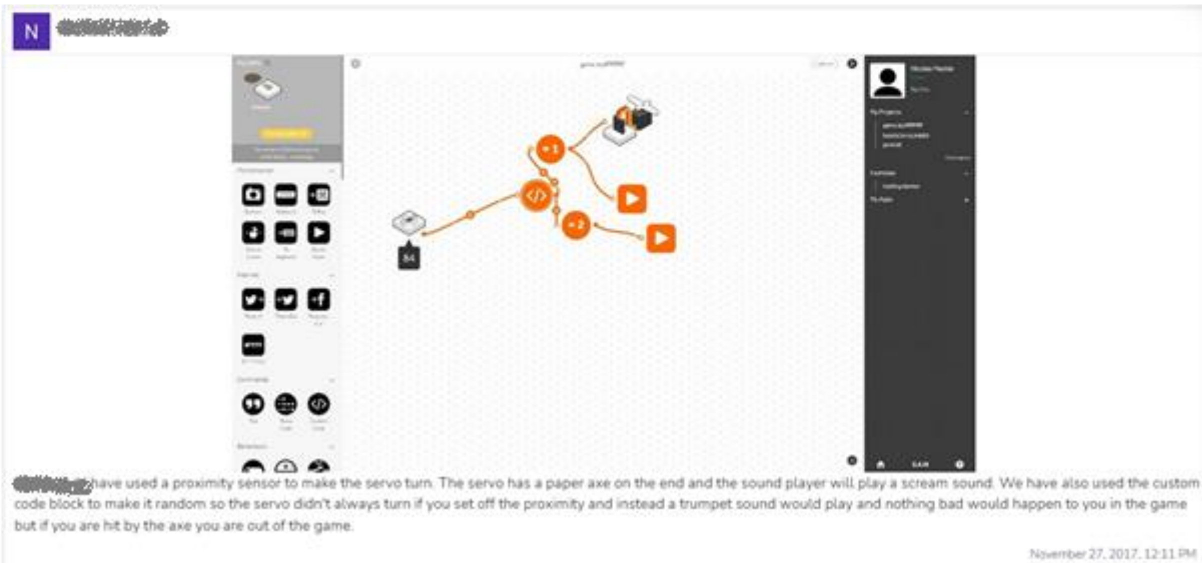
Sensor to trigger the ServoMotor, using a CodeModule and Comparator connectors to manage the proximity sensitivity and the timings of the sounds against the trapdoor movement: "I've got something really good here, hang on. It's going to go through the Delay, then it goes through the SAM player, then it goes.." "I'm almost there".

The 'Blocks and Connections' summarises the circuits used across Student N's trapdoor iterations, with an equal distribution amongst components:



The 'Kept versus Discarded' visualisation showcases most of the Student N's work as valid, with the iterations contributing to an adjusted implementation to better suit the board game, rather than fixing a functionality issue.





Conclusion

Student N completes the board game with only two SAM Labs elements. Whilst both designs are relatively complex, the Dice is implemented mostly with the teacher's help, leaving only the Trapdoor to be iterated on. Student N re-uses the Code Module from one component to another, and has a generally open attitude to testing and adapting his designs, however a hesitancy towards what is suitable to build in the first place results in little SAM Labs overall experimentation.

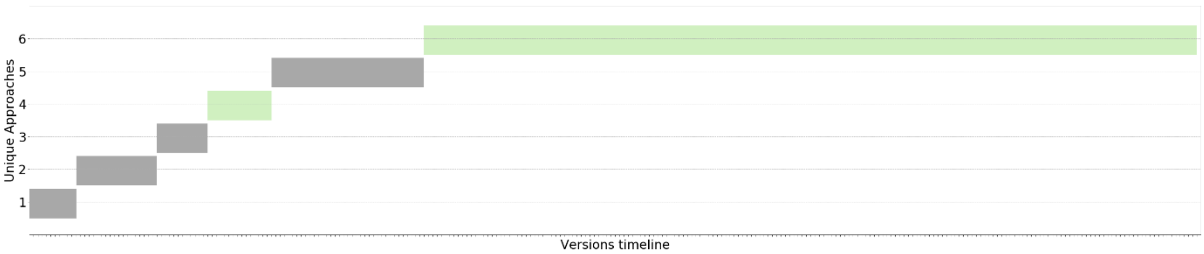
Student A

Student A, unlike Student K and Student N, starts the game with a few SAM Labs component ideas: “We’ll have a buzzer that buzzes how many spaces you can move” and “Underneath the box I will have a beheading center, you know one of those boxes with spikes that closes and then you die. Something like that, although that might be a bit too gruesome”, which make for the first instantiations of both the Dice and the Trapdoor ideas in the classroom.

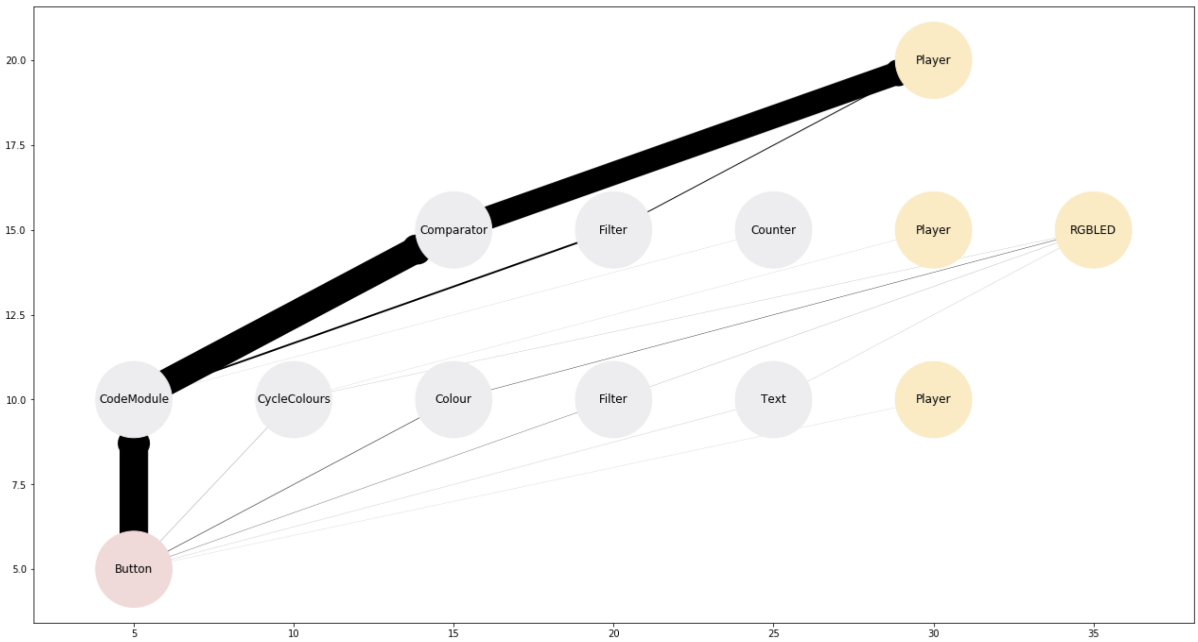
Dice

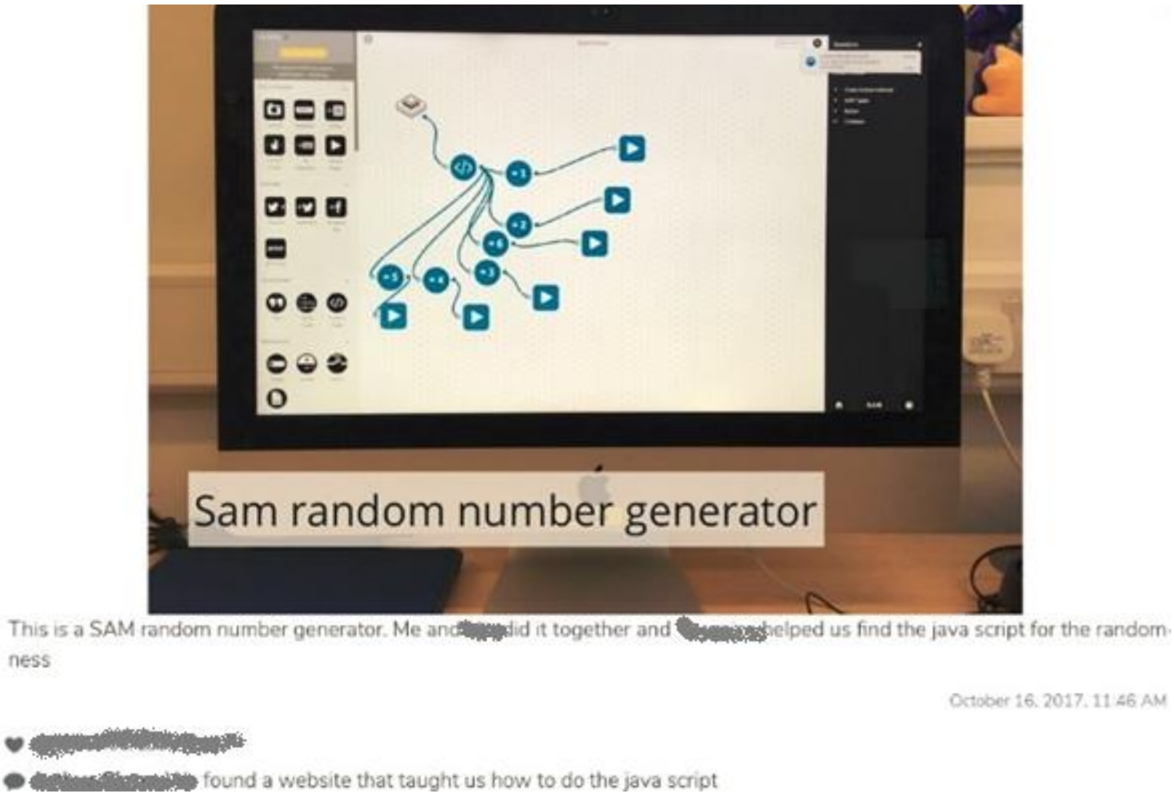
Student A is the student who joins Student N in copying the implementation of the Dice using the Code Module component, also new to him.

However, from the ‘Distinct Approaches’ visualisations, it is evident that the student attempts five different designs before deciding to use the same implementation as his friend:



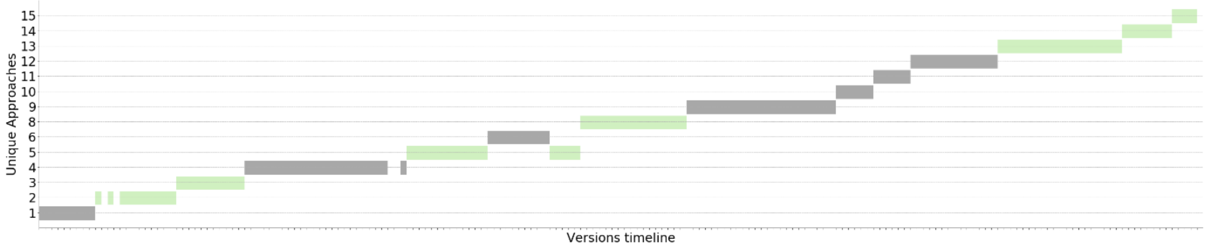
The five first designs are mostly invalid, and from the ‘Blocks and Connections’ visualisations it can be summarised that the first five approaches converge around using colours and lights to signal the different number of spaces players might move around the board. However, from the distribution of circuit usage, Student A spent most of his time testing the final circuit copied from his friend:





Landing Effect

The following component Student A works on is a Landing Effect for the players as they move around the board. He starts without a concrete goal, instead in his own words, he is happy to "mess around in SAM Labs education".
This attitude matches the view emerging from the 'Distinct Approaches' visualisation, which displays fourteen designs iterated through, roughly half invalid, before arriving at a final solution.



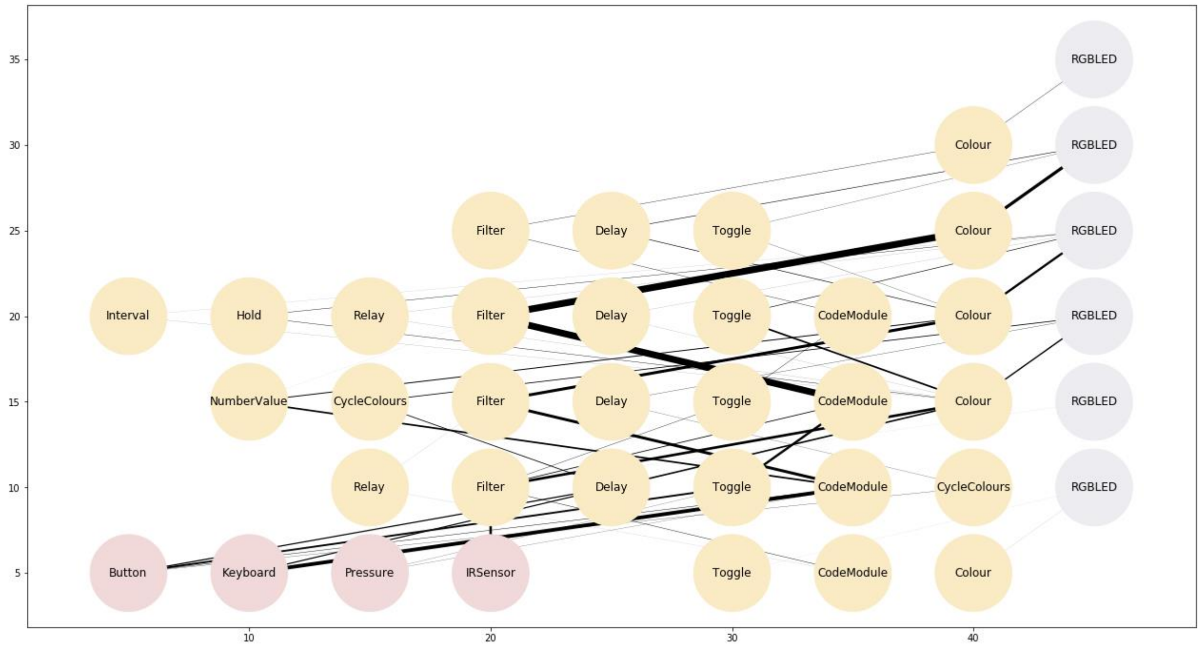
The first three designs are refinements to the same implementation using different coloured lights to indicate to the board game player which quiz-style question category they should pick up to answer. The exact use of the color is not fully defined: "After 5 seconds [..] it will output a color, and then should we make like.. Cards?" and when asked, Student A makes it clear he doesn't want to colour output to be randomised: "it's not [random], so they know what's coming next".

However, on the fourth version, he starts experimenting with ways of randomising the colors. He re-uses the Code Module functionality to achieve this in the fifth approach: "I've figured it out! I DID it! Random".

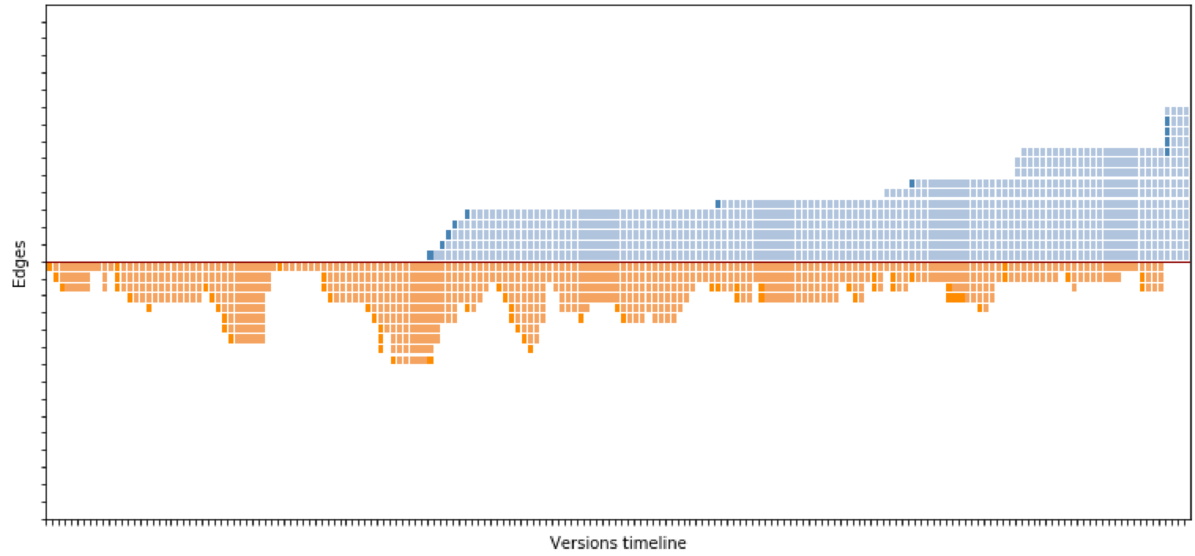
The teacher suggests a Pressure Pad to replace the Button, but Student A chooses a Proximity Sensor instead to have the functionality triggered automatically. However, the sensor doesn't work as expected, so Student A spends the next versions iterating through different configurations to make it work as he wants it to work. He is comfortable testing new circuits and uses debugging techniques like separating out a test circuit to isolate different parts of the functionality (SeeSaw).

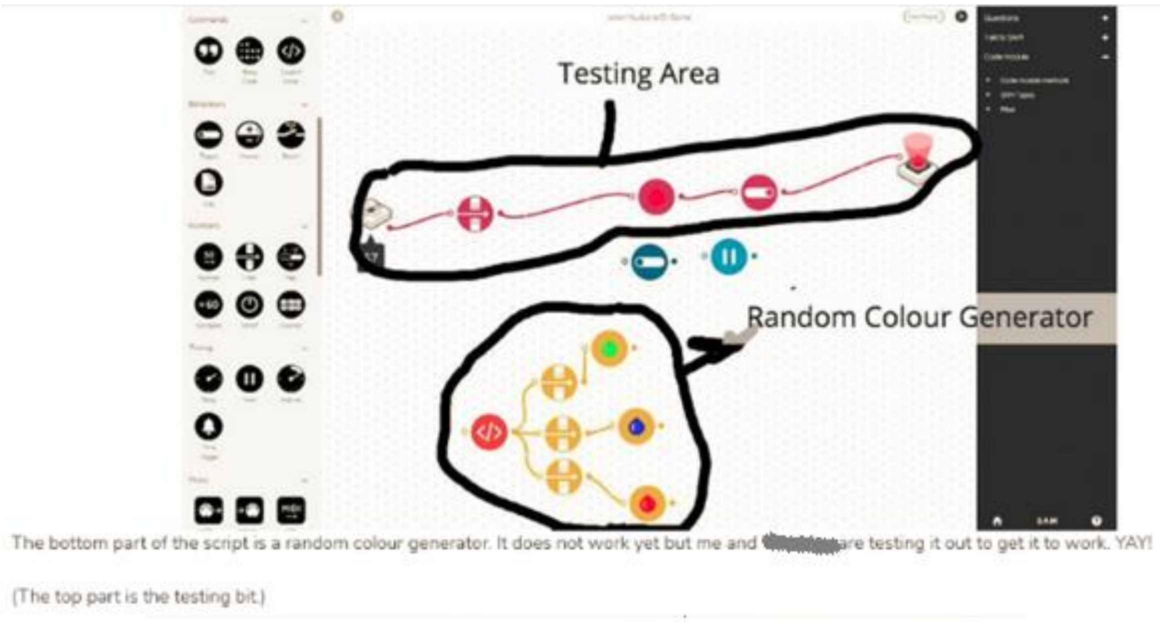
He is confident in his ability to troubleshoot, also reaching out to his teacher explaining the ways in which his design doesn't work, and the steps taken to fix it: “I think I’ve got it. I was trying it for a while, and every time, when I pressed it, it would switch to one color, and then change, and it would go back again. So if I did it again, it would be a different color, and if it’s the same color again…”

The ‘Blocks and Connections’ conveys the large number of components used in the multiple approaches:



The final design emerges gradually, as seen in the ‘Kept versus Discarded’ visualisation, from changes made halfway-through the project onwards, and with a steady amount of work discarded across the project timeline:

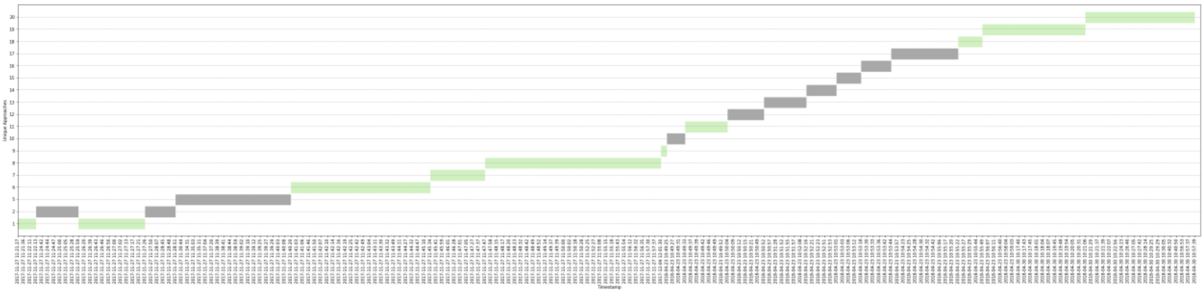




Trapdoor

For the implementation of his trapdoor, Student A initially envisages having a separate box as a ‘beheading center’, but this goal is refined in the context of the teacher’s suggestion of using a ServoMotor which opens a space on the board, so Student A adapts it to have the beheading centre inside the pizza box.

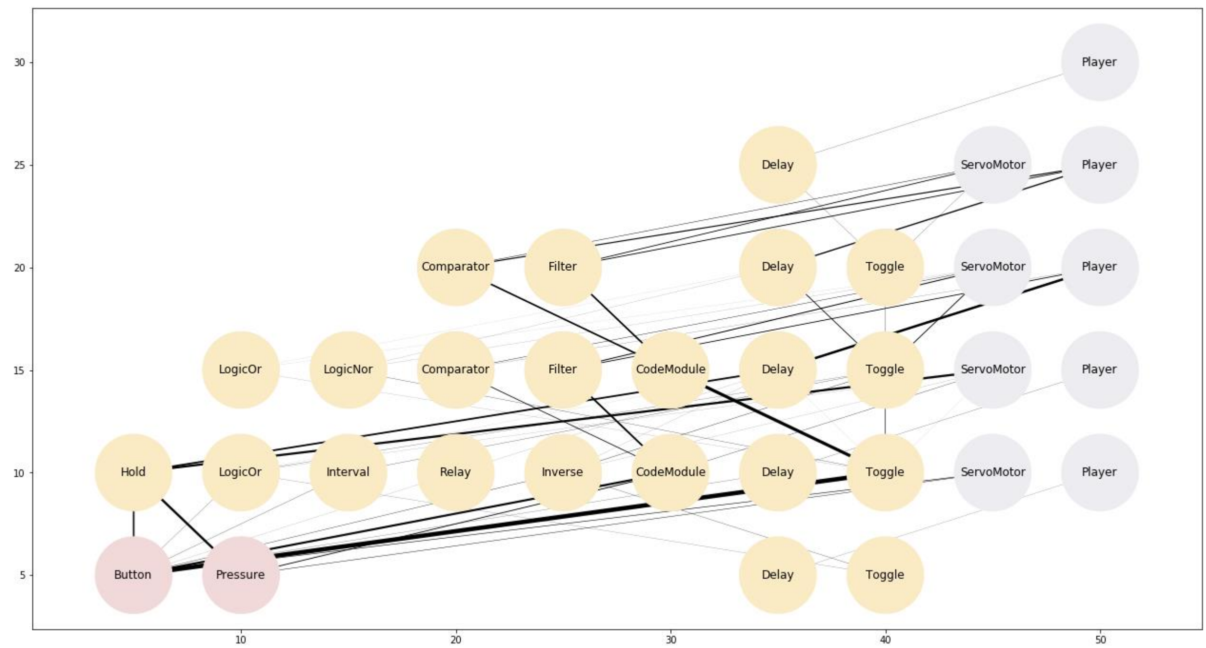
The ‘Distinct Approaches’ visualisation displays eighteen SAM Labs designs iterated through to arrive at a final Trapdoor design. The interactive version is available at https://b3qxre.axshare.com/home.html.



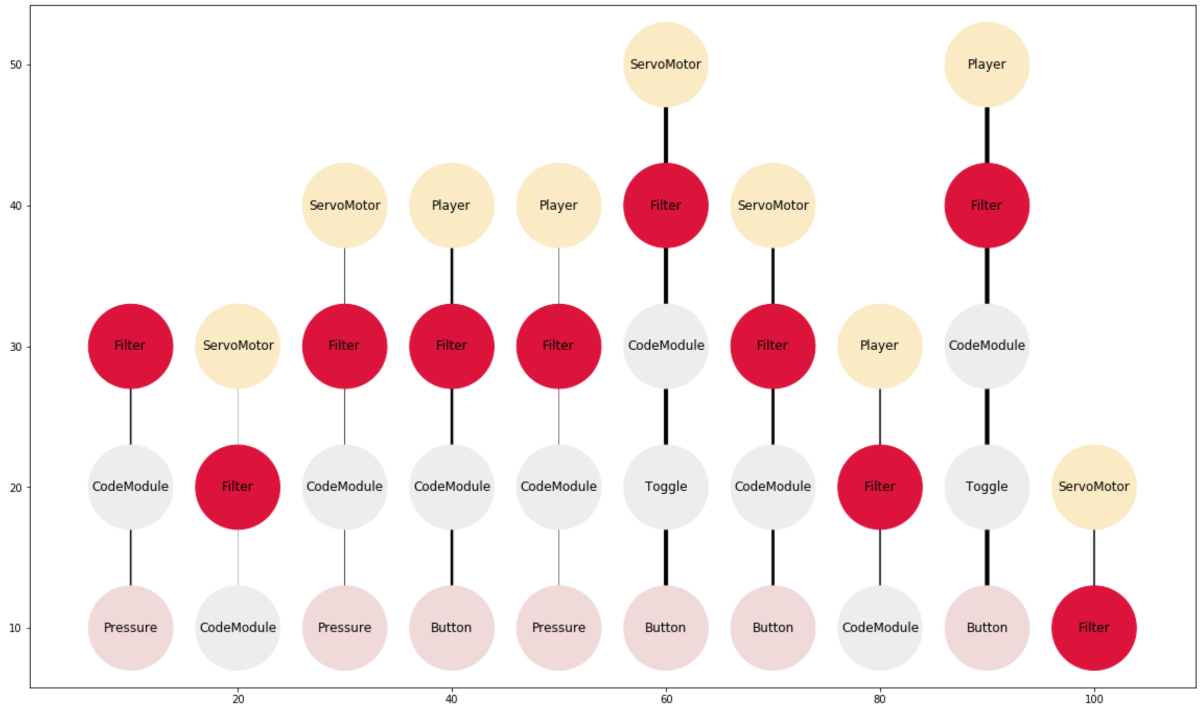
Student A starts with two simple designs, but quickly implements a third more complex circuit re-using the Code Module from the Dice implementation. The circuit fails to work consistently, despite being valid, so Student A keeps tweaking in small increments: “So if we put it between 0 and 1.. Doesn’t work :(“. Student A is happy to try different options out, and is fully engaged in thinking what other solutions might work: “So what if we do..”

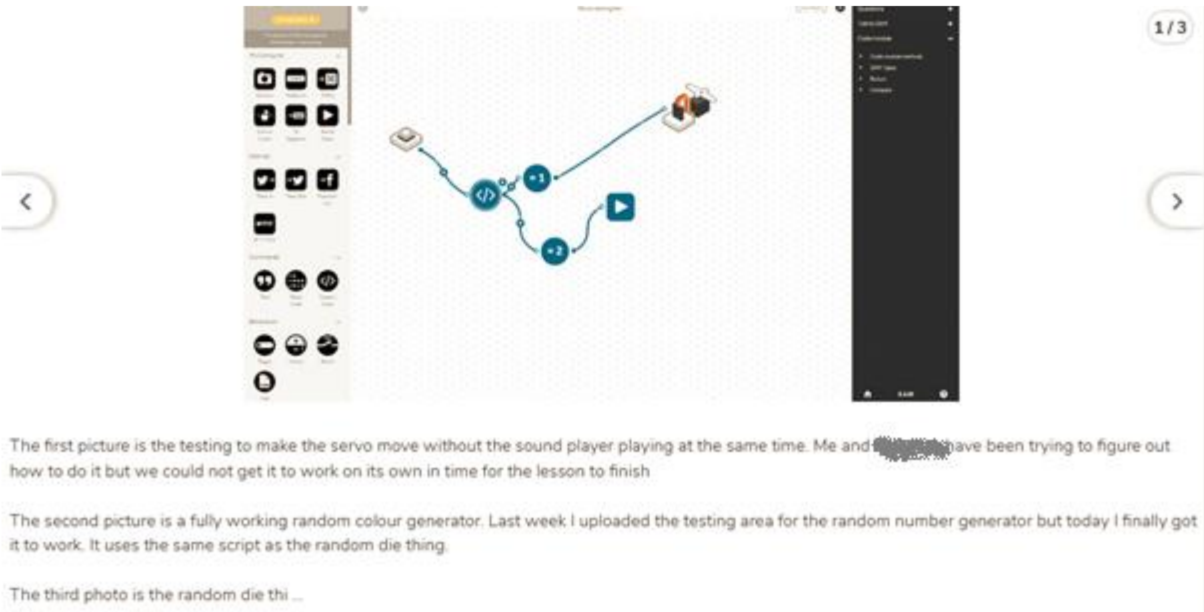
He also resists implementing fixes that, despite delivering a functional result, would make for clunky usage when playing the game: “Use 2 sound players, and if it says ‘off with his head’, there’s just another button and you press it for the axe to come down separately, and the servo goes..No”. The final Trapdoor solution is relatively simple, with a Pressure Sensor triggering both the ServoMotor to open to box and an accompanying sound, however, is the result of a high number of adaptations.

In the ’Blocks and Connections’ visualisation, Student A mostly iterates through distinct connector blocks between the same inputs: Button or Pressure Sensor, and the same outputs: ServoMotor and Player. The type of connectors used: Hold, Delay, Toggle, Inverse, Comparator, indicate the precision with which Student A seeks to control the trapdoor with, looking for a specific type of movement.



Equally, the 'Blocks across Contexts' visualisation for the Filter block shows small refinements of the same circuit, indicative of a search for a precise solution using the same components:





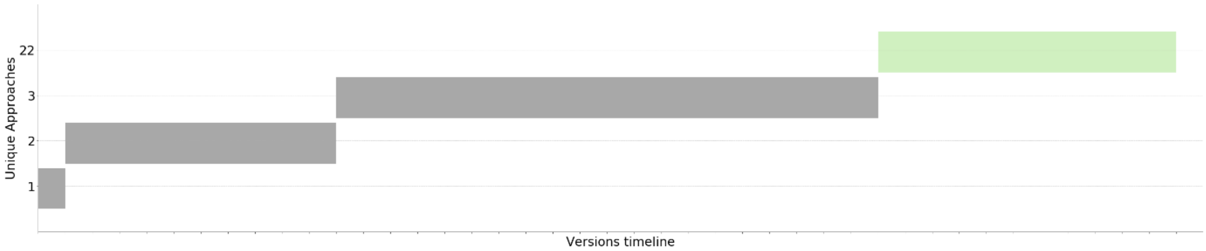
Conclusion

Student A shows a high degree of comfort both with using the SAM Labs blocks and engaging in an iterative design process to implement his components. As he iterates, he makes sure that whatever he tests is in line with his behaviours he seeks to implement: "But I need to get it random.. I tried putting each colour and when I press the button it would just do ..", and is happy to discard valid circuits which don't adhere to his goals.

Student J

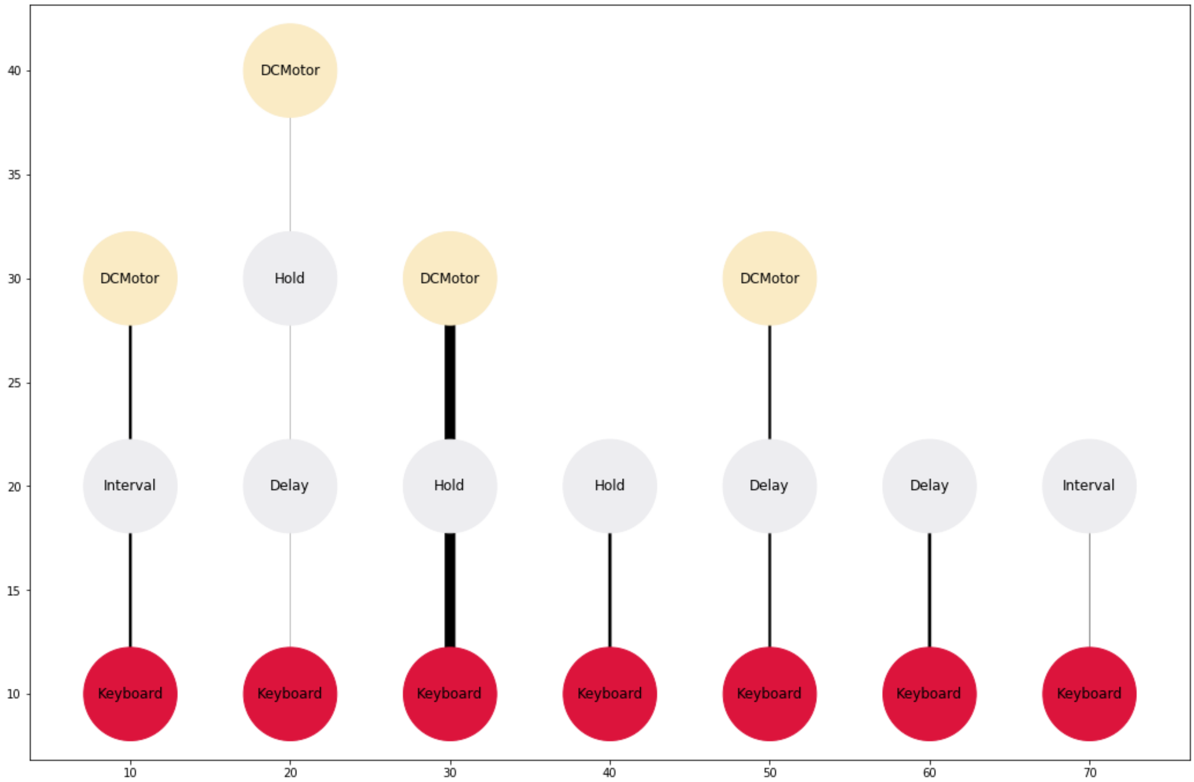
Student J generates several ideas at the start of the project: “I could do Trivial Pursuit. Or I can do PacMan or something like it”, “I could make a game like Monopoly Tudors, but that's not original”, but struggles to settle on one that he thinks is suitable: “I can't think of a good game... So, I’m trying to find other ideas. I'm gonna try to create more ideas”. Eventually, he settles on inventing his own board game rather than adapting an existing one. For the SAM Labs components, he talks through a few different ideas he intends to work on: "Going to use SAM for the buttons and the counters. There can be a speaker of some sorts that you can fit next to the character. If you move it there can be a SAM sensor in that place, so if you move it, it will play a sound", “I had the idea of a catapult” and having a True or False indicator for players after they answer quiz questions as they move on the board. However, none of these components get implemented. Instead, Student J works on a dice and a trapdoor, the same as the other students in the classroom, which he customises for his own board game rules.

Dice

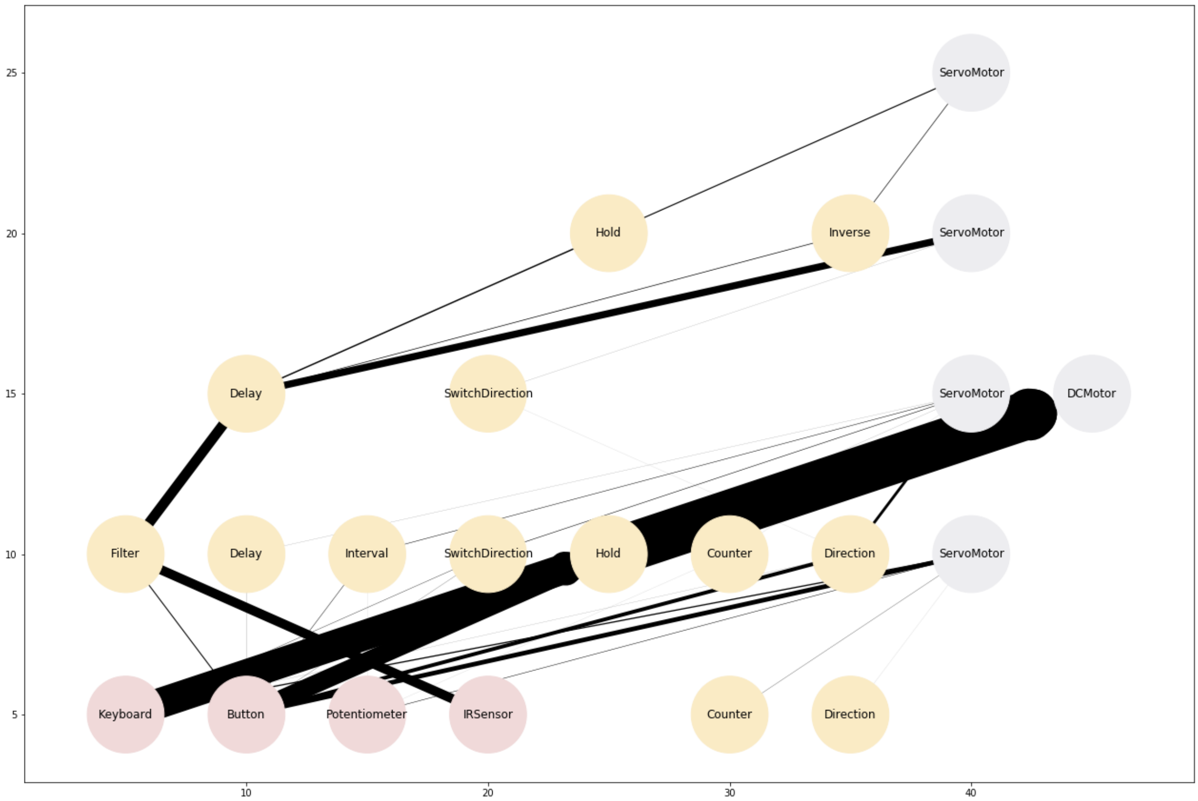


The construction of Student J's dice emerges from four distinct approaches. In the first three invalid versions, he tries different connections to generate a random effect: ”I need to make it random, but I don’t know how to do that”, "I don’t really, but I’m not sure how not to do that…I just kind of took it as a guess". His guesses have a logic to them, Student J connecting the same input and output through three different circuits to attempt a random effect through one of the three paths: “Yeah. I’ve tested it. And it spins on a random number. Well it’s not random but it’s got a different timing to it.”

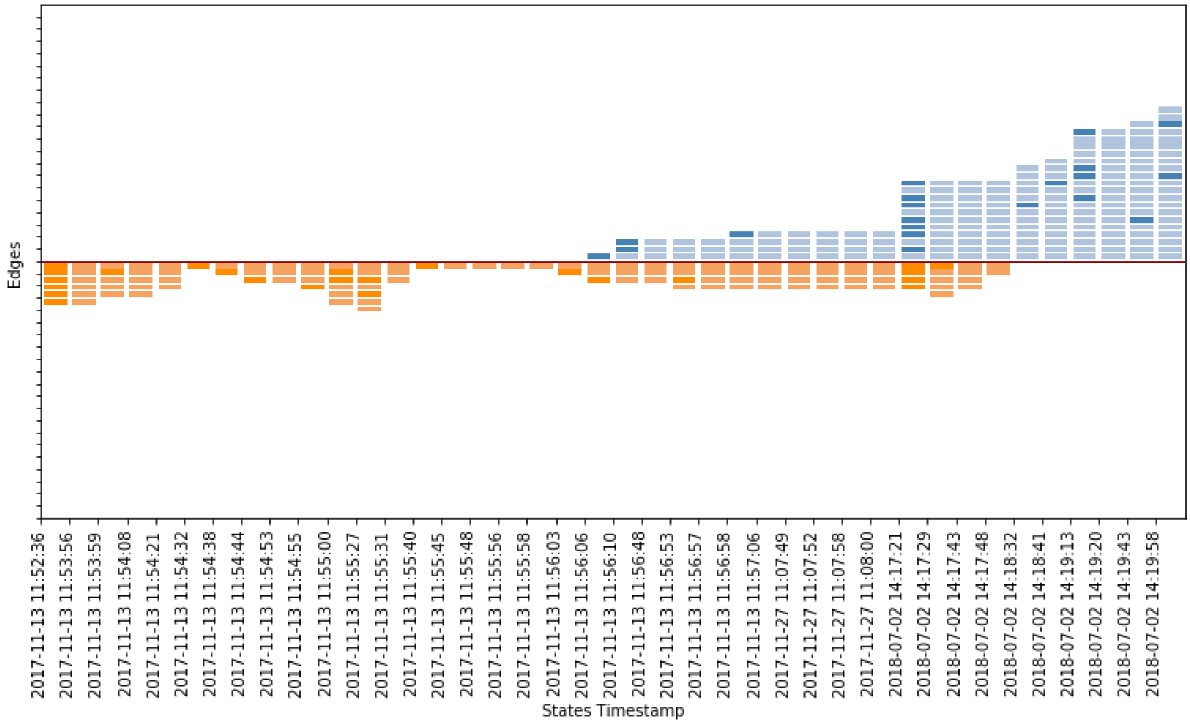
The ’Blocks across Contexts’ visualisation focused on the Keyboard input Student J uses as the input for his Dice shows the specific connectors he iterates through in order to arrive at the expected DCMotor movement, with the Hold making up the most attempts and remaining in the final Dice design.



The 'Blocks and Connections' visualisations also shows that, amongst all iterations, most are concentrated on the connectors that might change the Motor movement, with a high predominance of testing the Hold connector:

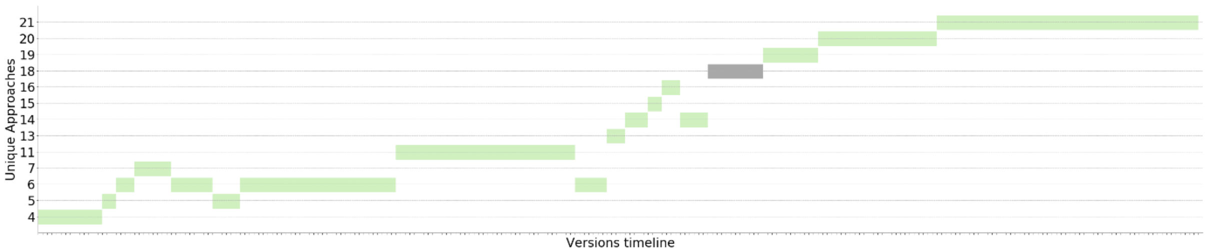


The overall volume of iterations is limited to finding the right connector to manipulate the DCMotor movement in a randomised way, resulting in a limited number of discarded work, and a final design that is built up gradually towards the end:



Trapdoor

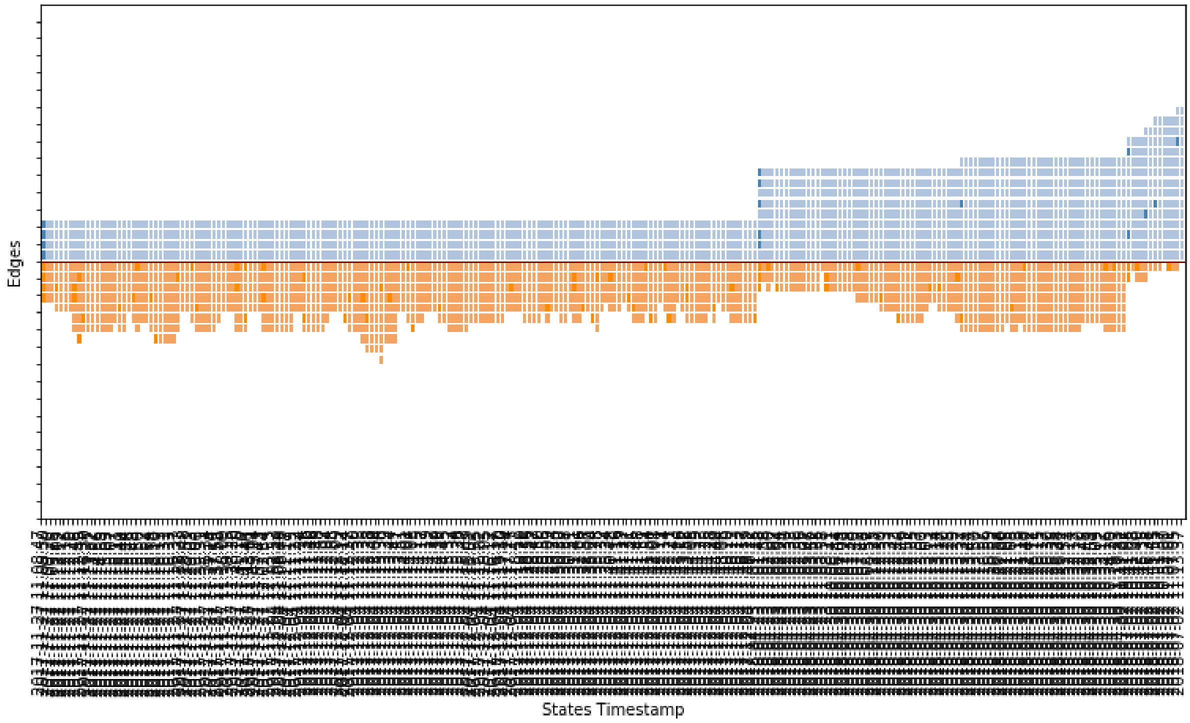
For his trapdoor, Student J spends longer iterating than his Dice implementation, working through thirteen distinct approaches. The interactive version is available at https://vru9mg.axshare.com/home.html.



In the first five versions, Student J goes back and forth testing the Button and Keyboard inputs, suspecting an issue with one of the Buttons: "I was having problems with the servo last week, and I was just testing, and the button doesn't work. When I click it, it doesn't work." After trying the Slider as well and not achieving the movement he wants, he changes his approach more radically to using an Inverse to control the direction, and a light sensor to trigger the motor.

For the last versions, Student J focuses on refining the way in which the trapdoor moves, the direction it opens and closes, for it to work well on the pizza board fitting. For the final design, he duplicates the design three times, for the three trapdoors he wants to have on the board.

The ‘Kept versus Discarded’ shows the final design is built up gradually from the start of the implementation, with work discarded consistently across the timeline:



Conclusion

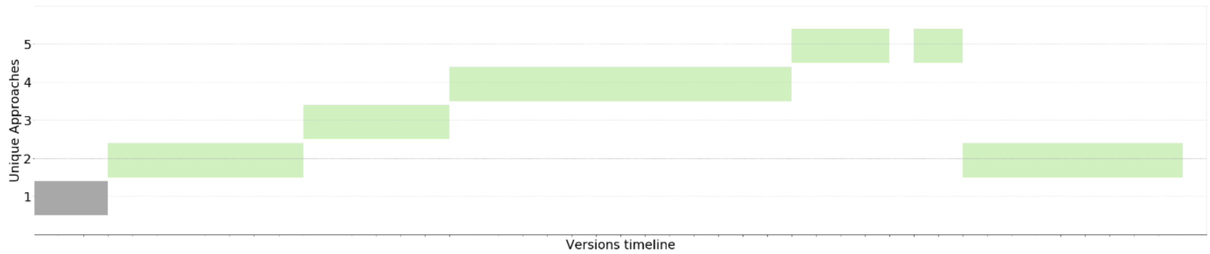
Despite struggling to identify the SAM Labs components to integrate into the board game, Student J expresses his comfort with testing different configurations once a goal is formulated: “I only introduced the servo into the project last week, so we had to play around with it, try and get it to work.” Sometimes it works, and sometimes it doesn’t.” “Well, I don’t know if it’s a button or a servo, so I’m testing it out.”.

Student R

Student R makes a keen start on the game, sure of his Monopoly adaptation idea: “I know EXACTLY how this is going to look”, but without fitting in and SAM Labs intelligent components: “We can forget about the SAMs, and just do it like that, like the original”

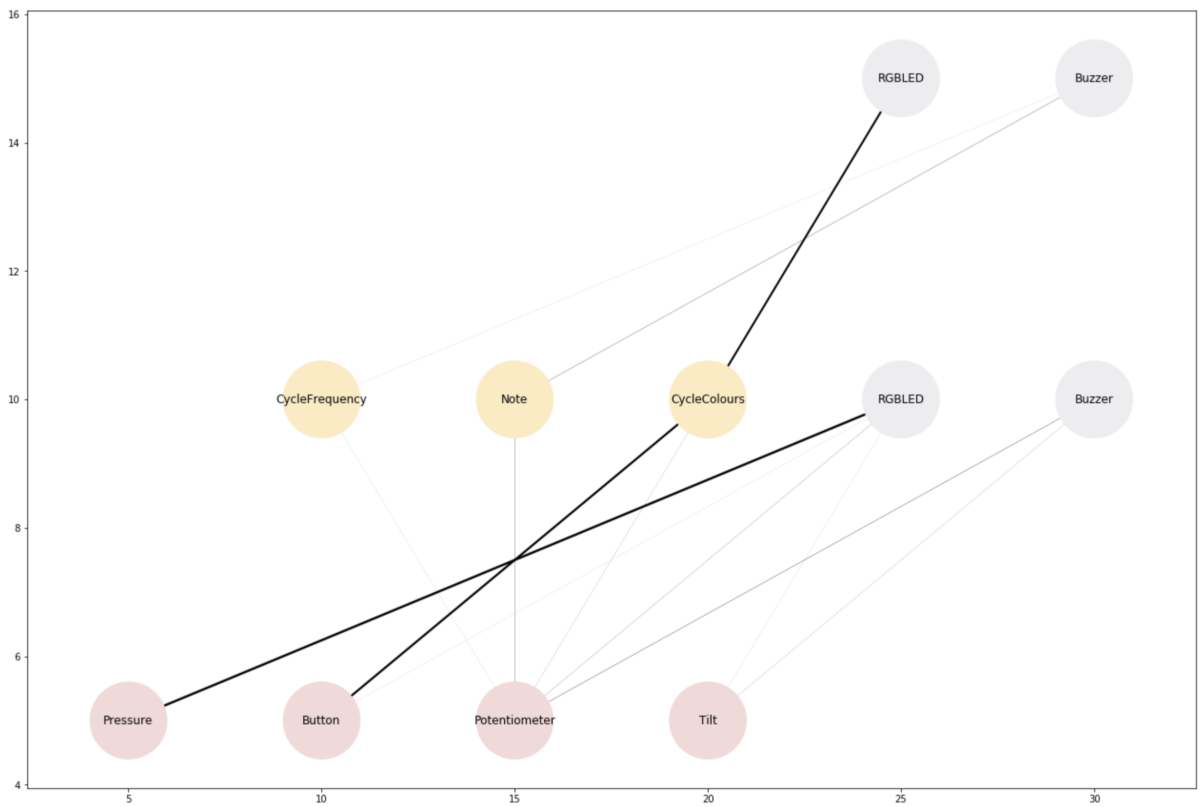
Dice and Lights

Eventually, he works of a Dice and Light effects at the same time, taking five approaches to reach a final design. The interactive version is available at https://dubmqm.axshare.com.

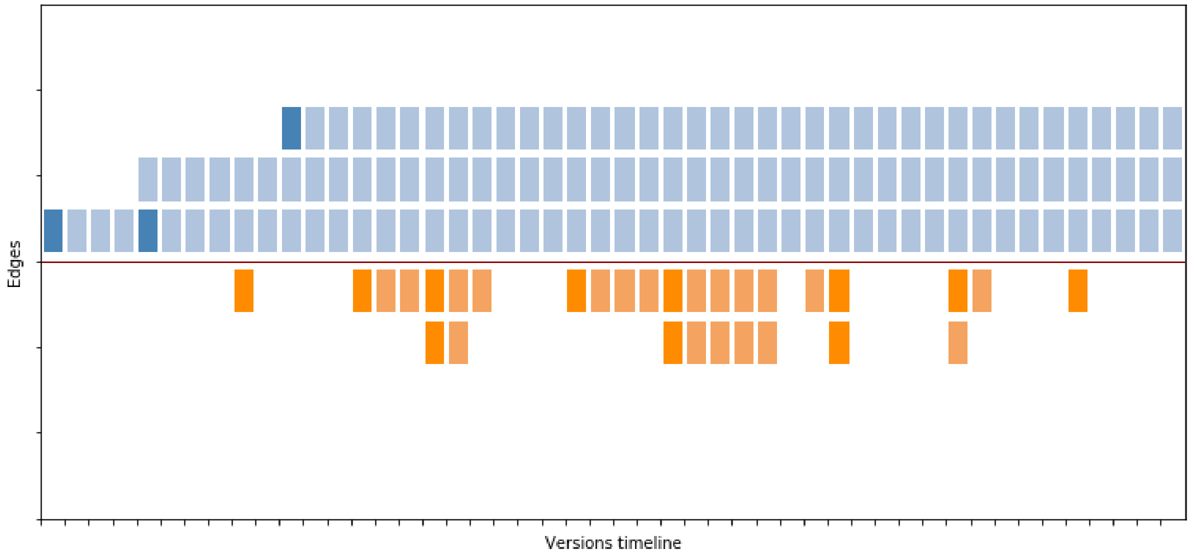


The exact use of the SAM Labs components on his board game emerges as he iterates through from one approach to the next. “So say 4, 1,2,3,4 on each corner of the board..”, “So when you land on Go you get a light, and when you land on Jail it will say ‘Go to Jail’… can it set off a buzzer?”, “That.. that.. I was thinking, maybe a buzzer. So if it was to buzz 2 times, you move twice, so you move as it buzzes.”

The ’Blocks and Connections’ visualisation paints a simple view of the components tested. Student R keeping his design simple, mostly made up of direct input->output circuits, with a single connector used for changing the colors of the light in the different corners of the board game.



The ‘Keep versus Discarded’ view also shows that Student R keeps most of the circuits he implements, with little discarded along the way:

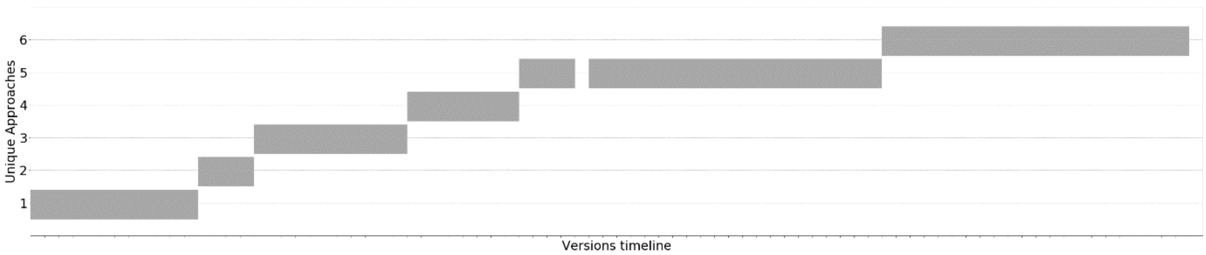


Student E

Student E is unsure about what to implement in SAM Labs, and constantly double-checks his ideas with the teacher, nervous of making mistakes: He constantly double-checks any SAM ideas, even before implementing anything with the teacher: "Could you have… I don't know how to put it… like a speaker, with SAM, to read out the question to you?" "Is that hard?" "So could you have something that you land on every square?" "So how would you do it?", and doesn't implement anything for the first three lessons.

Sound Effect

Finally, Student E works on a sound effect for his board, but he continues to seek constant reassurance as he iterates through the six invalid approaches. The interactive version is available at https://sdlp8n.axshare.com. "How do I do this?" "So what do I do with this? Where do I put it?" "Oh wait, I think I've got it. Is it here?" "Will it work when I do this?"

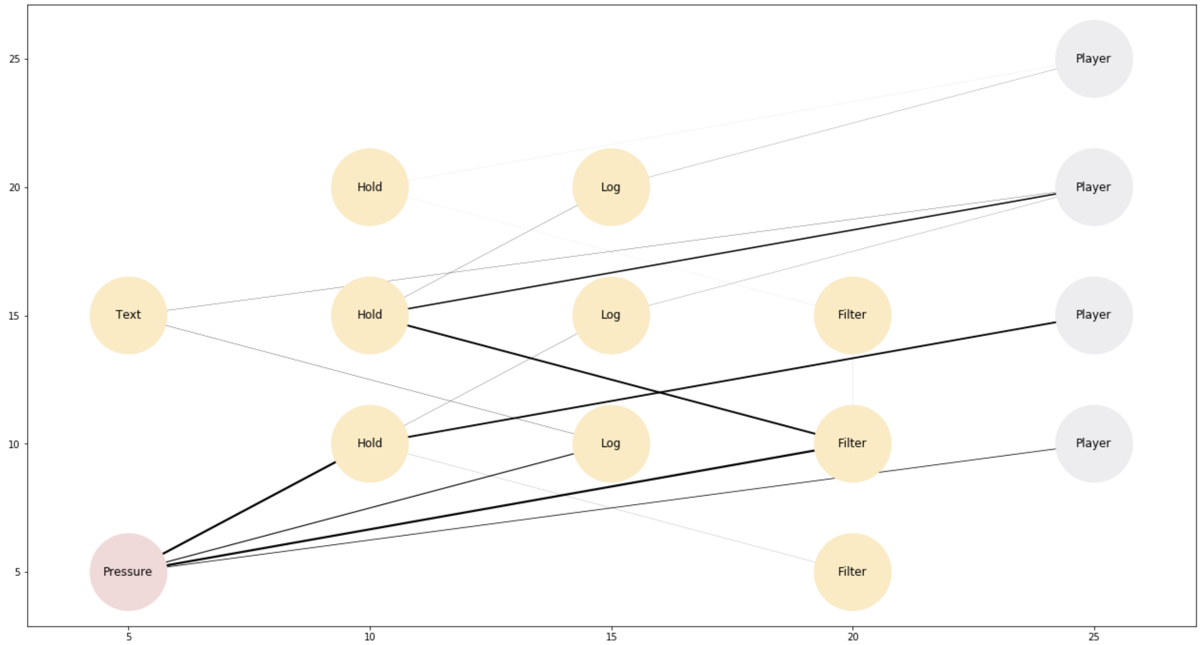


He implements the sound effect using a Player and a Pressure Sensor to trigger it, but struggles to manipulate the amount of pressure using the Filter block. He also uses a Hold to allow the Player to output sound for five seconds, but also uses this incorrectly. The final design is almost valid, one that does generate sound even if not exactly following the Filter instruction the student tried to implement. Therefore Student E keeps it partly working, reluctant to make any other changes that might render it completely unfunctional.

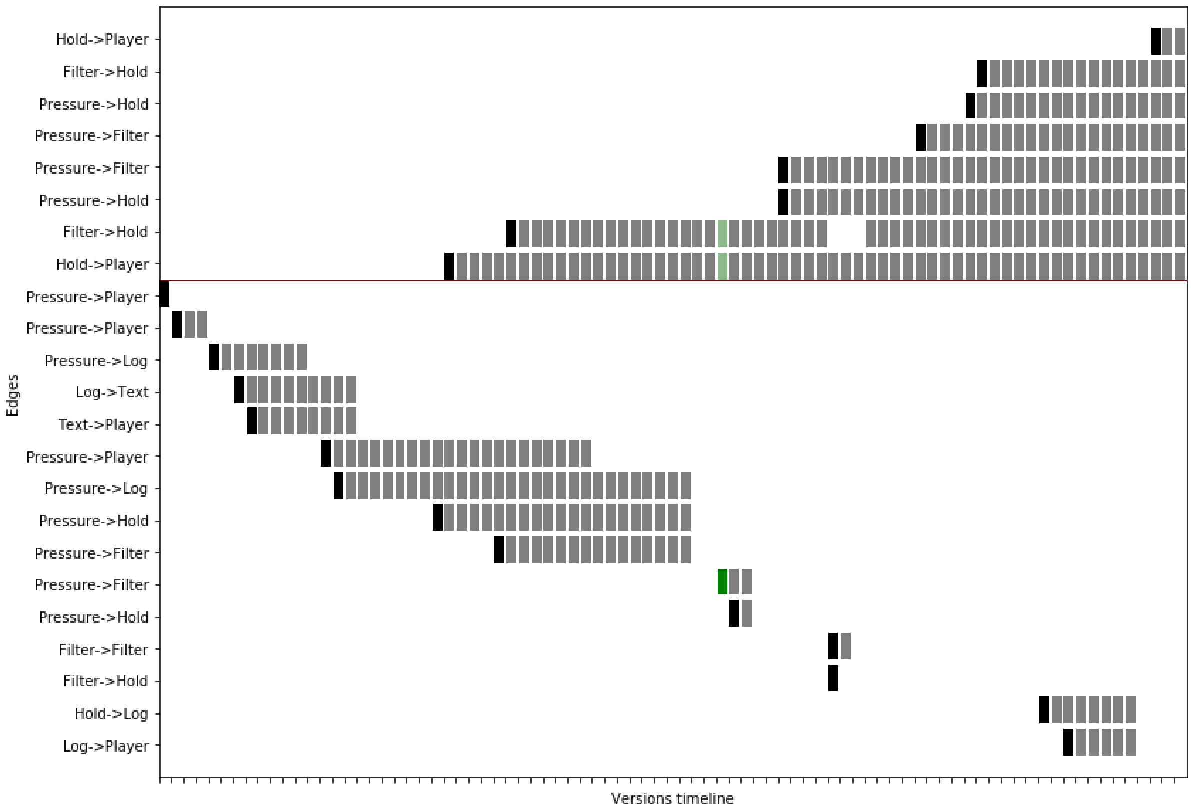
Conclusion

The six main adaptations are based on suggestions from the teacher, however the teacher stops short of giving him the answer, instead trying to nudge him into the right direction. He resists the encouragements to test the blocks, worried about making changes, and seeking guaranteed results: “Will it work when I do this?” Teacher: “Well, you’ll have to try it out.” Student E: “So will I need to change this?” Teacher: "You might need to adapt and try a few different options".

The ‘Blocks and Connections’ shows an attempt to connect the Pressure Pad to the Player through the Hold and Filter connector in almost every combination:



The ‘Kept versus Discarded’ visualisation with validity information shows that Student only builds invalid circuits:

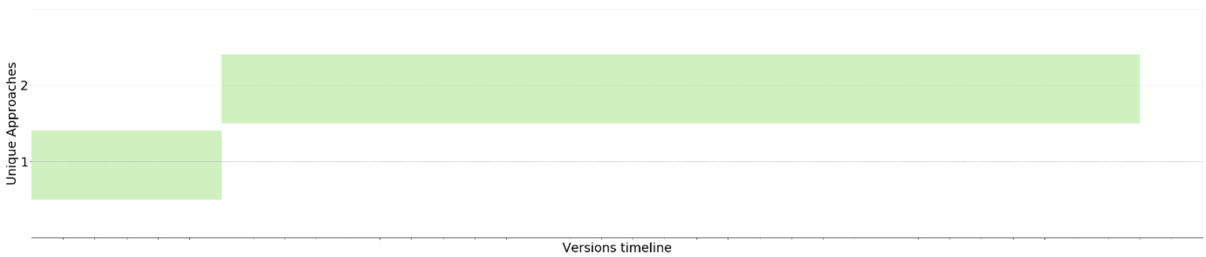


Student F

Student F implements his own invented board game rather than using a template based on an existing one. He generates complex SAM Labs components ideas, suggesting moving the players along the board with a horse and card, or using the Pressure Pads to generate and reveal digits of a code required to win the game, however none get implemented. Instead he keeps to three components for a dice, trapdoor and light effect, using very simple circuits.

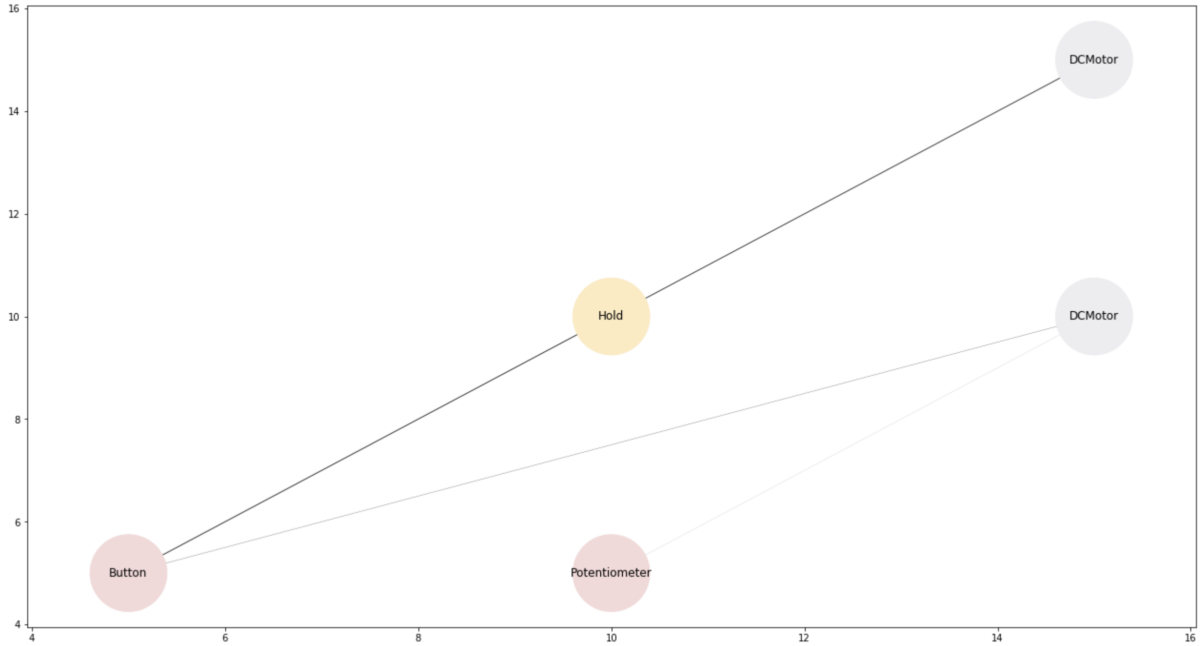
Dice

The interactive version is available at https://sou4px.axshare.com. Student F iterates little on his dice implementation, but ends very proud of his achievement: “It’s done. We’ve done it. We’ve only gone and done it!!!”



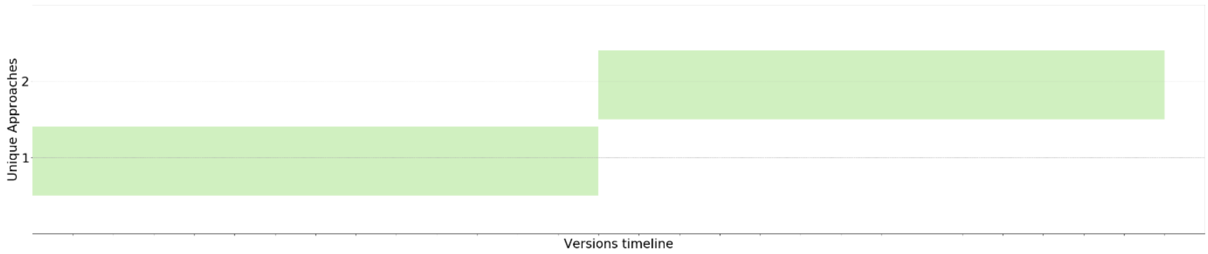
The single iteration involves adding a Hold connector as an attempt to randomise the Motor's movement. However Student F realises that a Hold won't quite achieve a random effect: "No but you can still actually time it with that".

The 'Blocks and Connections' visualisations is a quick summarisation of all the circuits implemented for the dice:



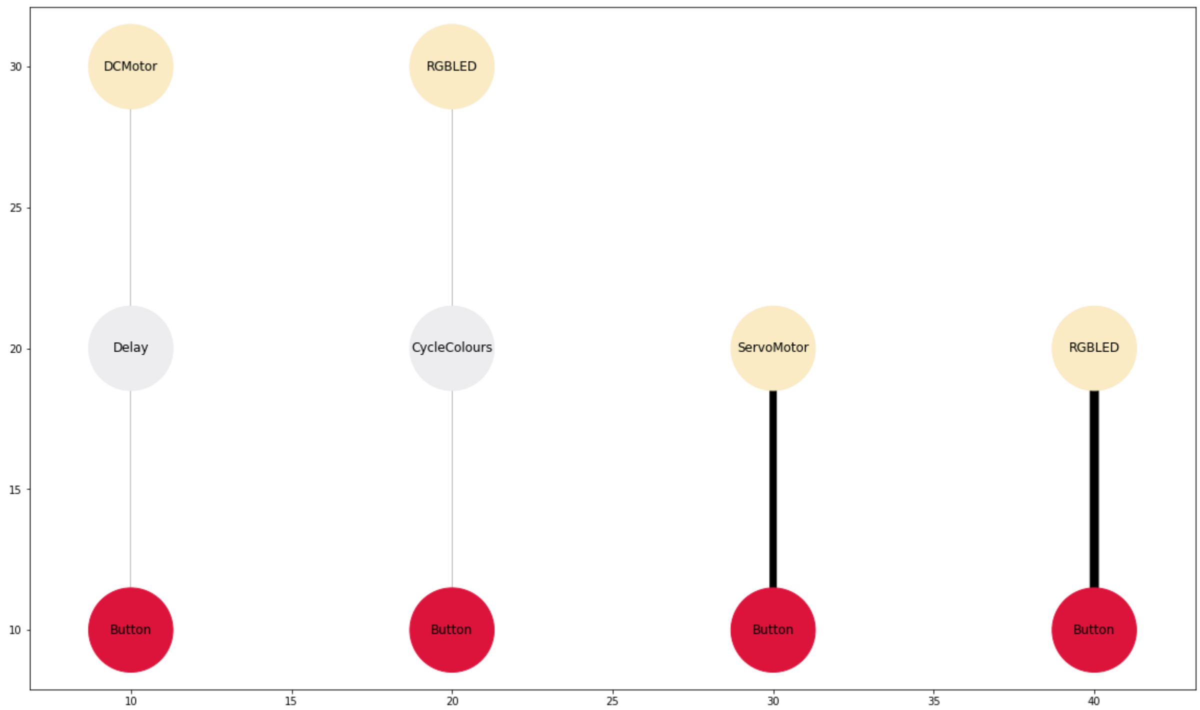
Trapdoor and Lights

For the trapdoor and the lights, Student F maintains the simplicity of his circuits and the low number of iterations:



The only adjustment is duplicating the same circuits multiple times, to be positioned in several places on the board: "We will have more than one servo-motor."

The "Blocks across Contexts" shows four different ways of using the Button as an input for his four game SAM Labs components, with no alternatives attempted:



Conclusion

Despite implementing very simple SAM Labs components, and almost not iterating at all, Student F's language around testing is indicative of perhaps a different attitude, which never materialises in his constructions: "It wasn't supposed to be final, it was just like a sketch.." "It's not perfect, but it's a start...". "This is a design project, first time we can try anything, trust me"

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