Investigating learning in secondary science students engaged in project-based learning

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This dissertation is submitted for the degree of Doctor of Philosophy

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Abstract

This thesis explores the nature of learning in students engaged in project-based learning (PBL) projects based in secondary science subjects. The literature review first establishes a working definition of learning, and then goes on the characterise project-based learning both in terms of its aims and associated methods. This gives rise to two research questions- how do students learn while engaged in project-based learning, and what effects to different aspects of project learning have on the learning taking place. The methodology then provides a rationale and description of the case study method selected to answer these questions.

The cases themselves are three students, pseudonymed Hamish, Hannah, and Jane, who were at the time of their participation Year 12 students at the local University Technical College (UTC), a school specialising in STEM subjects. The students were observed during weekly sessions of their Challenge projects, which represent PBL projects in a STEM subject completed with the collaboration of a local employer. Hamish's project focussed on the management and preservation of a local waterway, while Hannah and Jane worked on a Computer Science project featuring data visualisation and marketing. Each of the participants also completed a series of interviews about their experiences within the project, both in terms of the content knowledge and skills and in terms of their attitudes towards their projects.

What was revealed through these interviews was that even within the same projects, student learning and experience was variable. While all three participants met the objectives of their projects, they did so in different capacities, and appreciated the chance to do so. They also each had different responses to the delivery of their projects, based primarily on their own (reported) learning style. This was due primarily to the nature of the projects, and the autonomy students were encouraged to show throughout the project.

A work of this magnitude is never completed in isolation; it truly took a village to construct this thesis, even if all the writing is my own original content. First and foremost, I want to thank my supervisor Keith Taber for his unfailing support, often provided with a level of sarcasm and dry humour matched only by my own. My supervisor Mark was also a source of guidance, and his advice led me down the path that ultimately led to this thesis

Next I want to thank my Dad, who has been my hero and my inspiration since the day I was born. You never gave up on me, and I'm here today because of you. Mom, Joe, Kristen-nobody could ask for a better family, or rather they could but they wouldn't find one.

I never would have made it through these last three years without my person, Catalina, who rowed with me, complained about rowing with me, introduced me to the procrastination tool known as Grey's Anatomy, and was there every time I needed a shoulder to cry on. The hardest part of finishing this degree is knowing that you'll no longer be a short cycle ride away.

I'd like to also thank every one of the dozens if not hundreds of individuals I've rowed or coxed with over the years. Being a small part of TWO blade-winning campaigns was more than I ever imagined, and a special thank-you goes to Hughes for bringing me on board in every conceivable capacity over the last several years. Cantabs also thank you for making me part of the family in my final year, and for giving me a chance to experience the wonder that is Garfield.

Through rowing I also met some incredible people who made my time here a joy. Sonja, Sammy, Evelyn, Isabella...I could go on. I've been very blessed in this regard. Matt deserves a particular thank you for not only helping me gain a better understanding of Computer Science but also enduring the stream of messages on nearly every topic whenever I needed someone to talk to. You've been my friends when I needed them most, and I am forever grateful.

I made it here because of my students, both past and future. To the young men and women who encouraged me to pursue this degree and have regularly reminded me over the past three years of why I am here, I owe an immeasurable debt of gratitude. I in the most literal sense would not be submitting this thesis without them.

Each participant in my research gave me a better understanding of the student experience, and though they are anonymous, I thank each of them, whether they spent one interview session with me or twenty. Truly you were the heart and soul of this PhD, and I and everyone who reads this will benefit greatly from your stories.

Finally, I submit this PhD here in memory of my grandfather, Richard Dobrin who passed away during my first year, and made sure the last words he ever spoke to me were "I'm proud of you and I love you". I'd never have considered this path for myself without your encouragement and example, and that you did not live to see this day is harder on me than you could possibly imagine. I love you now and forever.

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CHAPTER 1- Review of existing literature

1.1. Introduction

This thesis was undertaken to build upon existing research into project-based learning (PBL), with particular attention to such learning in the secondary science classroom. At present, there is relatively little research into this teaching method at the secondary level, and even less into the particular subset of PBL projects that were of interest here. What will follow then is an account of three students, 'Hamish', 'Hannah', and 'Jane', who agreed to participate in research relating to their learning through the unique projects offered by their sixth form college. In order to provide sufficient detail into their stories, a case study method was adopted, with each student being treated as an individual case. The findings will be discussed in Chapters 3-6, and the implications for these findings will follow.

In order to provide appropriate context for these findings, I find it necessary to begin by explaining my background, and how this has likely shaped the collection, analysis, and presentation of the data contained herein. As an undergraduate, I triple majored[1] in Biology, Veterinary Science, and Psychology (with an emphasis in Animal Behaviour). My coursework was heavily lab-based, including the Psychology courses, where much was done on the basis of what was readily observable. My early years as an educator were much the same, with most of my decision-making being influenced by observed classroom behaviours and assessment statistics. It was only with time that I began to consider outcomes that could not be measured or observed, and it was when this occurred that I began to give thought to the context I was providing for the students.

Context in science education is not particularly easy for all teachers to provide (Fensham, 2009) but is often a vital component of the learning process (Watts, 1994 p.41):

> Science needs to be relevant to students' everyday lives since this real context provides the roots from which their studies *should* be drawn. It needs to be related to their hobbies and modern lifestyles; to current affairs and television news; to people and practices in the world; to ideas and creative thinking at work; to economic and industrial success

[1] In the US, students select one (sometimes two and rarely three) major areas of study, in addition to an (optional) minor area, as well as some general education courses

Watts' words above, written at a time when, according to Fensham (2009), many national bodies were cutting context from the science curriculum, mirror many of the conversations I had as an early career educator in the early 2010's. These conversations were not limited to fellow educators either; the students were aware enough of their own learning preferences to express a preference for contextualised learning, which I made every effort to provide.

It was a conversation in late 2015 regarding this preference for context and personal relevance that led to this current investigation. I had a number of students who had become frustrated with the immense quantity of curriculum-mandated material, and reported feeling disengaged. They were uninspired by the practicals associated with the topic, redox processes, and requested a change. As a solution, each student was sent home to investigate a particular issue that was relevant to them and related to redox processes. The response was incredible; students came forward with examples of redox reactions in every field from Biology to historical preservation, and they were driven to push their investigations beyond the scope of the syllabus. Though I was at that time limited by time, resources, and school guidelines, I decided then that a proper investigation of student-centred practical work within authentic contexts was warranted, which led to pursuit of this thesis.

1.2. The scope of this work

As suggested above, the purpose of this work is to investigate student learning in authentic contexts, and in this work that is through the use of real-world project-based learning (PBL^2) projects. Rather than focus specifically on providing context within individual lessons or across teaching methods, this research focusses quite specifically on one method of providing real-world context, the PBL project. In this chapter, I will endeavour to provide coherent definitions of many of the ideas mentioned here, such as learning, PBL, context, and student outcomes. I will also introduce the University Technical College (UTC) concept, which is currently quite unique and yet also part of a growing movement to reshape the face of secondary

[2] In some sources, PBL is used interchangeably for both project-based and problem-based learning. Other places use PBL for problem-based and PjBL for project-based. Here, I will only be using the abbreviation to stand for project-based learning.

and post-16 education. The next chapter will outline the theoretical and practical considerations that frame the methodology, provide additional information about the school setting, and outline the specific methods of data collection and analysis. The bulk of this work will then be dedicated to chapters relating to the three individuals who participated in this research, Hamish, Hannah, and Jane (pseudonyms). Each case relates to the experience of the individual student in a single project, and to conclude this work the implications of each case will be explored. It would be impossible to in a single work explore every experience or perspective relating to these projects, but it is my hope that this work will represent a new and significant perspective on what it means for students to learn in an authentic PBL environment.

1.3. Defining learning

1.3 .1. Learning in common use

One of the difficulties science teachers often report is that students come to the classroom with prior conceptions of certain scientific phenomena which are not always accurate. A prime example of this is students' early conceptions of gravity. Klopfer, Champagne, and Gunstone (1983) report that students may come to the Physics classroom with the notion that heavier objects fall faster than lighter ones (so gravity must pull more on heavier objects), based on examples from their everyday life. These conceptions contradict the more accurate conceptions they encounter, which can make the learner more resistant to learning the scientific conceptions their instruction is designed to expose them to (Pintrich, Marx, & Boyle, 1993). This is also potentially true of other concepts, such as learning. Learning as a theme is prevalent in all aspects of culture including music, film, and literature (of a recreational rather than academic nature). Popular songs on the radio or memes on the internet make use of the term 'learning' without providing context, and so it was worth considering whether or not this would influence understanding of what learning is, and what learning is not.

While in some instances the task of sorting out academically acceptable conceptions from common use ones is quite onerous, this proved not to be true of learning. In fact, it may actually prove quite difficult to find a common definition of learning that does not share a significant portion of its characteristics with one supported by the academic community. Certainly there are a wealth of songs by both contemporary and classic artists that refer implicitly to learning in

terms compatible with the definitions offered below, particularly behavioural change as a result of experience. The question then becomes, which academic community's perspectives on learning should form the basis of this investigation? It would be extremely tempting to rely solely on the views of educational practitioners, as those in closest contact with the students whose learning forms the focal point of this research. The problems arise when two practitioners have different standards for learning, and this is where considering learning from the perspectives of researcher, both in education and in psychology, will allow for the building of a robust image of learning from considering the overlap and thus possibly determining the critical characteristics.

1.3.2. Learning from a psychological perspective

Psychology is undeniably a diverse field; paradigms such as humanism and behaviourism each attempt to explain behaviour, often in contradiction to one another. To argue then that it is possible to consider learning from a single, unified psychological perspective would be disingenuous at best. It is not the purpose of this work to assert the overall validity of one over the other, only to select a paradigm which is most compatible with the research being undertaken. Based on the background of the researcher and the practitioner perspectives (discussed below), that paradigm is behaviourism. From the behaviourist's perspective, learning is primarily tied to behaviour, in that learning will lead to changes in said behaviour. Behaviourism is therefore most likely to be concerned with observable changes to behaviour, which would thereby imply that learning has taken place. Not all changes in behaviour qualify as learning, however; Olson and Hergenhahn (2009) break down Kimble's (1961) definition of learning to consider the following characteristics as essential:

-Learning translates into an observable behaviour
-Changes are relatively permanent
-The changes need not be immediate, though the potential now exists
-The changes result from practice, or experience
-These practices and experiences must be reinforced

This of course at best provides a foundation upon which to begin the discussion of exactly what constitutes learning. Olson and Hergenhahn's definition would not, for example, include behavioural changes that are the result of drugs or other temporary chemical intervention. There is also some debate over what is meant by reinforcement; while some may view reinforcement to be synonymous with reward, Skinner (1986) among others feel that this is inaccurate. The difference is perhaps quite subtle, but a reward is worked for, whereas a reinforcement is a natural consequence of a certain behaviour.

Another element of Olson and Hergenhahn's definition of learning that needs to be considered is the element of observable behaviour. In essence, whatever mental processes that occur must result in a change in observable behaviour in order to constitute learning. Because the change need not be immediate, however, it is possible to allow for learning which creates the potential for new behaviours that has not yet been realised. Determining what qualifies as behaviour also presents some challenge. If we look again at the common usage, it can be seen as "the way in which one acts or conducts oneself, especially towards others" or "the way in which an animal or person behaves in response to a particular situation or stimulus" (OUP, 2019). Within the scientific community there are both agreements and disagreements with this common usage. Skinner, for example, believed that thoughts and other internal acts constituted behaviour worthy of study, whereas John Watson (1931) disagreed, in favour of only those behaviours which were readily observable by researchers (p.6; italics reproduced from original):

> Now what can we observe? We can observe *behavior- what it is the organism does or says.* And let us point out at once: that *saying* is doing- that is, *behaving*. Speaking overtly or to ourselves (thinking) is just as objective a type of behavior as baseball.

While Watson's words have been challenged and adapted over time (Skinner's *radical behaviourism* being one example) and the field of Psychology has changed with advances in neuroimaging and indeed simply with current trends, there is some merit in his definition here. Academic achievement is recorded in terms of measurable and achievable outcomes, and so any investigation into the educational experience might well consider why these behaviours are the ones most valued in practice. It is important here to note that not every observable outcome

necessarily represents learning (Hattie, 2008), as some goals may be met without any real change to the students' behavioural potential.

Another consideration regards what can be considered a stimulus. Again, there are many opinions on this. Dewey (1909), widely considered to be a seminal force within the field of educational psychology, felt that thinking was triggered only by specific stimuli, which are often (though not exclusively) associated with prior experience. Watson (1931) elaborated, considering both external stimuli such as flashes of light, and internal stimuli such as the contraction of the stomach muscles, as triggers of changes to behaviour[3]. For the purposes then of this thesis, learning from the adopted psychological perspective shall be considered *the creation of the potential for a relatively permanent behaviour as a result of reinforced practice or experience,* with behaviour being understood to be an objective and observable action that may include speech or thought.

1.3.3. Learning from a practitioner perspective

As suggested above, the practitioner perspective in education is focussed primarily on observable behaviours, and the assessment of these. These observable behaviours, often referred to as teaching or learning outcomes, are often presented as hierarchical in nature, thanks in part to the influence of Bloom's (1956) taxonomy of educational objectives, the first volume of which focussed on the cognitive domain. Because of the ubiquitous nature of this work, most practitioners are familiar with some iteration of the taxonomy, often presented in pyramid form as shown in Figure 1.1 below:

[3] A discussion of conditioned stimuli and responses would seem to be the natural next step in such a discussion. However, this is beyond the scope of this work, and it is therefore being assumed that such stimuli are being presented to the students through their practice and experience

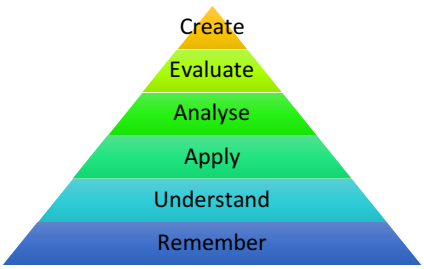

Figure 1.1. Taxonomy of educational objectives, derived from the work of Bloom (1956)

In most instances, this taxonomy is applied to determine the depth to which a student is able to operate with a certain fact or concept. Learning in these cases might be seen as the ability of students to move 'up' from one taxonomic level to the next. Anderson et al. (2001) revised Bloom's original taxonomy by considering the cognitive process dimension in concert with what they refer to as the knowledge dimension. This is often presented as a table, as seen below:

Table 1.1. Anderson et al. (2001)'s Taxonomy for learning, teaching, and assessing. A revision of Bloom's (1956) original

The Knowledge Dimension	The Cognitive Process Dimension					
	Remember	Understand	Apply	Analyze	Evaluate	Create
A. Factual Knowledge						
B. Conceptual Knowledge						
C. Procedural Knowledge						
D. Metacognitive Knowledge						

This taxonomy not only maintains the hierarchy of cognitive processes associated with knowledge, it creates one regarding the types of knowledge expected as well; factual knowledge represents the basic elements of a knowledge structure, conceptual knowledge begins to build an awareness of that structure, procedural begins to allow for manipulation within that structure, and metacognitive knowledge includes both strategic knowledge and an awareness of one's own learning. Most of these outcomes will be discussed later on in this work.

The taxonomy that will have the most influence on the research here is Fink (2013). Fink's focus has been at the post-secondary level, but incorporates much of what Bloom and Anderson et al. brought to their taxonomies with one significant difference: Fink's taxonomy is non-hierarchical. Rather, Fink views learning as relational, and feels that this is critical in that it

removes the expectation that one type of learning must be sacrificed to allow for another. Fink, like many of the psychologists mentioned in § 1.3.2. believes that learning is considered to be the *change* in behaviours that fall within the various domains of his taxonomy, seen in Figure 1.2, below:

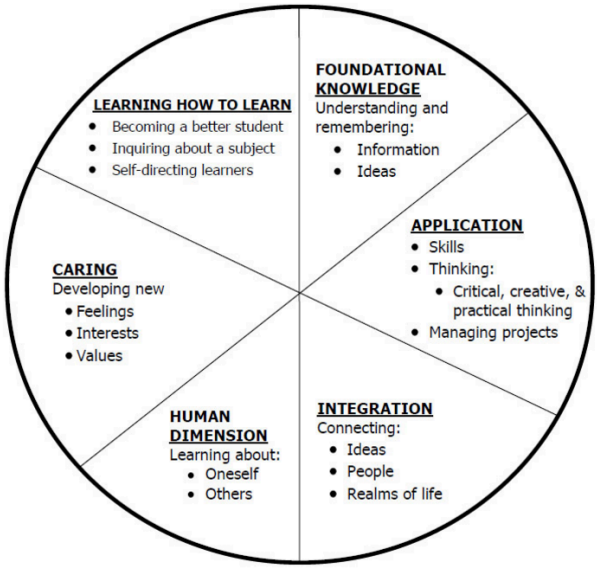

Figure1.2 Taxonomy of significant learning, from Fink (2013). Reproduced with permission of the publisher

Fink's model is designed to be more interactive, for the express purpose of creating learning experiences which are significant to the learner. This means the construction not only of subject-related knowledge, but of skills with a wide range of applicability even after the completion of formal education. Many of these more transferrable skills will be addressed further in terms of outcomes later on, but it is worth taking note of them here, in terms of defining learning.

1.4. Learning Outcomes

1.4.1. Learning in terms of conceptual change

It has already been established that the observable behaviours subject to change as the result of learning need not be limited to physical actions; conscious thought can also shift as a result of student experience, and this may imply change in the conceptual ecology (Posner et al. 1982) of the learner. This conceptual ecology is unique to each individual learner. Students may form different rules for inclusion within a concept (Kellogg, 1995), leading to concepts which vary from one individual to the next. However, many categorisations seem to be universal rather than

situational, as individuals tend to form natural categories through minimal external input (Taber, 2002). Take for example Reif (1985)'s example of a "generic concept" or "variable", the triangle. A young learner may be able to identify a shape as triangular, even without checking the summation of internal angles or possessing any information regarding trigonometric ratios. A young learner may also be able to identify from a series of images "birds" without having been taught anything of physiology or genetics, using instead a simple, natural dichotomous classification or assign membership based on prototype examples. The student may assign different properties, themselves a form of concept, to their conceptions as a means of classifying them.

Learner conceptions may be either implicit or explicit (Gunstone, 1994; White & Gunstone, 1992), meaning the student might not even be aware of the properties they assign to a particular concept. This also has implications for the ways students are able to describe or explain their conceptions. The student may not be able to articulate *why* a particular shape is not a triangle, or why a penguin is a bird but a bat is not, but the conception may still exist. As learners develop a more advanced understanding of the concept, they may be able to articulate their understanding of it in different ways, such as those described by Reif (1985). The student may be able first to provide a concise, "summary description" of the concept (in terms of physics, **a**=dv/dt), reciting almost formulaically rules for inclusion within the concept. The "informal description" mentioned next may be vague but still highlight essential qualities "acceleration is rate of change of velocity with time" (p.137). The "procedural specification" involves a much more specific breakdown of the concept, relating it to a specific instance and involving additional variables or concepts in the process. Reif notes that this procedural specification may lead to student discontent with their concepts, as they may reveal contradictions. It is as this happens that conceptual change may start to occur.

Given the lack of coherent consensus on what constitutes a concept, it is unsurprising that there is likewise a wide diversity in the definition of conceptual change. It is widely acknowledged that learners often enter the learning space with prior, intuitive, or naïve knowledge of scientific phenomena (Brass & Duke, 1994; Champagne, Gunstone, & Klopfer, 1985a & 1985b; Loyens, Jones, Mikkers, & van Gog, 2015; Reif, 1985). Learners may enter the physics classroom with their own conceptions of motion or energy (for example), based on their experiences. Many of the naïve conceptions or explanations possessed by young learners are quite resistant to change

(Brown & Hammer, 2003; Champagne et al., 1985a & 1985b; Wittrock, 1994) when their experience-based views are at odds with accepted scientific principles and concepts. Champagne et al.(1985a) also posit that student conceptions influence the way they experience, remember, and understand future lessons, which is in line with a constructivist viewpoint.

Learners will often cling to their prior conceptions even when at odds with observations, to the point of designing additional experiments to prove an exception (Gunstone et al., 1985). This adherence to prior conceptions becomes even more determined when these prior connections are seemingly reinforced by what is perceived as fact, such as the idea that a heavier object will fall faster than a lighter object *because gravity exerts more pull on the object with greater mass* (Klopfer, Champagne, & Gunstone, 1983). It is however through connections to prior conceptions that new, more accepted conceptions are able to be constructed (Watts 1994), though it is possible that in some instances, this prior knowledge can adversely affect student learning (Champagne, Gunstone, & Klopfer, 1983) and so must be considered with care. It is not sufficient to simply inform the learner that their conceptions are inaccurate or incomplete and therefore need development; the learner themselves must become dissatisfied with their current conceptions before any change can occur (Gunstone, 1994). After this, conceptual change in some form may take place.

The form this change may take is also often disputed. While "there is likely no single truth to explain the complex process of conceptual change" (Özdemir & Clark, 2007, p. 359), two perspectives on the coherence of knowledge (Table 1.2) tend to lend support to either revolutionary or evolutionary change (Özdemir & Clark, 2007). The predominant perspective for many years, knowledge-as-theory, posits that conceptions exist as part of a cohesive network of naïve knowledge that is, over time, replaced by (what are hopefully) scientific conceptions. Carey (1985) offers an example of the knowledge-as-theory perspective, wherein children's naïve theories are, over time, replaced with more advanced theories. Özdemir and Clark (2007) propose that, if a knowledge-as-theory perspective guides instruction, the curriculum should focus on circumstances that will allow the learner to become dissatisfied with their existing conceptions. An example of such a circumstance is the pre-discussion phase of problem-based learning (Loyens et al., 2015). As students communicate the prior knowledge they possess to solve the problem presented, they may find that knowledge inadequate to understand the problem.

Driver, Leach, Scott, and Wood-Robinson (1994) would suggest that replacement of one theory with another is an oversimplification of a much more complex process, however. In recent years, research has supported a knowledge-as-elements perspective wherein knowledge exists as individual concepts loosely linked in a network. DiSessa's (1993) p-prims are an illustrative example of this perspective, wherein different elements of the knowledge structure may be activated with varying priority in different contexts. Wittrock (1994) also suggests that learning is activated in certain contexts, and suggests that these contexts be as realistic as possible so as to allow for students to believe in their experiences, rather than view them as manipulated exceptions. Driver, Leach, Scott, and Wood-Robinson (1994) also suggest that determining a context involves taking into account prior knowledge for it to be accessible to students. Cycling of matter, for example, would be more readily accepted in terms of decomposition in soil than photosynthesis if the learner does not yet have a conception of gas-as-matter. This may be seen as an example of evolutionary rather than revolutionary change.

Table 1.2. Summary comparison of knowledge-as-elements and knowledge-as-theory perspectives

Agreements	
Learners acquire knowledge from their daily experiences.	
Learners' naïve knowledge influences their formal learning.	
Much naïve knowledge is highly resistant to change. Thus, conceptual change is a time consuming process.	
Disagreements	
Knowledge-as-Theory Perspectives	**Knowledge-as-Elements Perspectives**
Naïve knowledge is highly organized in theory, schema, or frame forms.	Naïve knowledge is a collection of quasi-independent knowledge elements.
Naïve knowledge in a coherent form has explanatory power to consistently interpret the situations across broad domains.	Consistent application over time for individual contexts, and systematicities will be present, but high contextual sensitivity.
More focus on revolutionary replacement of naïve knowledge in a manner similar to Kuhn's perspectives on paradigms in science. Significant coherence between ideas at any given point in time.	More focus on conceptual change involving evolutionary revision, refinement, and reorganization. Multiple conflicting ideas may coexist simultaneously at any given point in time.
Explanations involve the creation of mental models constrained through the overarching framework theories or ontological categories.	Explanations involve the p-prims and other elements within the learner's conceptual ecology that are most strongly cued by the context.

Note: Reproduced from "an overview of conceptual change theories," by G. Özdemir & D.B. Clark, 2007, *Eurasia Journal of Mathematics, Science and Technology Education*, *3*(4), p. 355. Copyright 2007 by Moment. Reprinted under the terms of the journal's open access policy

1.4.2. Learning in terms of transferrable skills

From the literature on learning from the view of both the psychologist and the educational practitioner, it is clear that learning is not limited to conceptual change. While much of standardised assessment focusses on the learning of facts or concepts, skills, often referred to as 'soft skills' or 'transferrable skills', are considered to be critical to the workplace (McCrone, White, Kettlewell, Sims, & Rush, 2019), everyday life (Taber, 2016), or to undergraduate study. Skills such as communication and problem-solving in particular are valued in considering the admission of students to elite universities (C. Cangea, personal communication, March 29, 2019) as they represent potential to work with material on a more involved level. As seen above, Anderson et al. (2001) and Fink (2013) both include within their learning taxonomies several items that do not necessarily fit in to the description of conceptual learning provided in the preceding section. What then constitutes a transferrable skill, and how are they acquired?

Much of the existing literature is in general agreement regarding many of these skills, while industry-specific publications may include more or less depending on those most valued in the field. Carvalho (2016) lists several transferrable skills in the context of problem-based learning: problem-solving skills and attitudes, communication, leadership and interpersonal competencies, adaptability, self-reflection and personal development. Carvalho writes from the perspective of field of management studies, but there appears to be a great deal of similarity in the natural sciences as well. Canelas, Hill, and Novicki (2017) suggest that problem-solving, communication, leadership, and collaboration are transferrable skills that can be learned in the Organic Chemistry classroom and thereafter applied in workplace situations, and Bailey, Minderhout, and Loertscher (2012) propose application, analysis, and problem-solving as key transferrable skills in the Biochemistry classroom. The National Association of Colleges and Employers, in their annual job outlook, list several of these among their most sought-after skills as reported by employers, with communication skills (written), problem-solving skills, ability to work in a team, initiative, and analytical/quantitative skills listed at the five most desirable (NACE, 2019).

Having established then a general understanding of what constitutes a transferrable skill, it is now necessary to consider how best these might be developed. Since learning has been defined to include change in behavioural potential, it may be assumed that for students to learn

transferrable skills, they must be exposed to opportunities in which these transferrable skills are necessary. Carvalho (2016) found that a problem-based learning model was conducive to the development of some transferrable skills, specifically information searching and teamwork. Mills and Treagust (2003) report that engineering "students who participate in project-based learning…demonstrate better teamwork and communication skills. They have a better understanding of the application of their knowledge in practice". Taber (2016) mentions that while many of the skills listed here (there called generic skills) may be learned within subject-specific study such as chemistry, the learning of these skills is enhanced by being developed through a wide range of curriculum contexts.

Transferrable skills may be developed in any subject; Kafai and Burke (2014) argue for example that "in learning to write code, children can learn to articulate procedures, recognize repetition, and "debug" their own thinking" (p23), key features of computational thinking and yet also seen in many other subjects, particularly within STEM. Gorman (2010) found that students who participated in a long-term water quality monitoring project were more analytical, reflective, and willing to suggest improvements to investigations than were students in purely lecture-based settings as well. This idea of learning these skills, whether they are referred to as 'soft', 'life', 'generic', or 'transferrable', through the learning of content-related or procedural skills seems to be nearly universally accepted. Sibthorp (2003) focussed more on *how* the learning of the transferrable skills takes place, and found that it was largely by learning though doing. Moreover, when students were presented with authentic scenarios they were forced by the nature of the project to develop a more diverse and often transferrable skill set.

Novak and Krajcik (2019) for example investigated a semester long PBL project into the water quality of a local stream, completed by middle school[4] students as part of their science instruction. Students were given a high degree of freedom in determining what data to collect and which tests to perform, and were allowed to be iterative in their designs, so each data-gathering episode refined their process. This led to greater problem-solving, communication, and argumentation from evidence. Such a design was deliberate to allow for the integration of core science content, scientific practices, and crosscutting concepts (CCC's) which form a component of the curriculum. These CCC's, which included cause and effect, patterns, systems,

[4] Key stage 3

stability, and change (Novak and Krajcik, 2019), are not explicitly transferrable in that they relate specifically to science and engineering, but do represent an effort to organise understanding across disciplines. Integrating these with the other components of the project to produce a scientific explanation that can be communicated to the community required many transferrable skills in an authentic learning environment.

Vogler et al. (2018) were also concerned with the authenticity of the PBL project they reported on, explicitly tying their definition of authenticity with the skills developed and utilised throughout the project. It is clear from context that this applies to the soft (transferrable) skills as well as the subject specific ones; in this interdisciplinary project across computer science, hotel/restaurant administration (HRAD), and graphic design, students had to work collaboratively within their discipline and communicate effectively to those on other tracks to successfully complete their project. These skills, they argue, are identical to those that would form the basis of teamwork in actual post-graduation workplaces. Of note in the Vogler et al. (2018) study however, is their finding that while soft skills are more universal that industry-specific technical ones, different disciplines related more to certain soft skills than others. Computer scientists, they found, most commonly referred to lifelong learning, while the HRAD students alone explicitly commented on the development of their communication skills. Teamwork and collaboration, however, was mentioned by students in all three disciplines.

Perhaps most interesting and relevant for providing context to PBL in STEM subjects is that while proficiency in programming languages was considered by Vogler et al. to be a hard skill, use of information technology was considered a soft (transferrable) skill. Hard skills in HRAD focussed mainly on market research, but communication and lifelong learning were again listed as soft skills. This suggests that some skills may exist on a context-specific spectrum; the line between hard and soft not as clear as research may suggest. It is also undeniable from the research that the development of these soft, transferrable skills is facilitated by the construction of more discipline-specific, hard skills, and that the reverse holds true as well. Engagement in argument from evidence, a scientific practice listed by Novak and Krajcik (2019), would require skills in observation, research, and communication even as it enhances those same skills. It is those softer skills that the learner might carry on to other courses, or into their daily lives as graduates.

How then do these skills, both the transferrable ones and the technical skills intertwined with them, constitute learning? Anderson et al. (2001)'s taxonomy (Table 1.1) certainly allows for transferrable skills development in nearly all cognitive process dimensions, depending on project design. Across the knowledge dimension, procedural knowledge may relate to problem-solving, planning, and communicating, while metacognitive knowledge, an awareness of one's thinking and learning, is undeniably transferrable across disciplines and ties in with the lifelong learning mentioned by students in Vogler et al (2018)'s study. Fink's (2013) taxonomy explicitly acknowledges the development of skills, critical, creative, and practical thinking, managing projects, learning how to learn, among others. According to Fink's interactive taxonomy (Figure 4.1), it may in fact be considered crucial that this learning be integrated with content knowledge or subject-specific technical skills in order for the learning to be significant. Integration may also be a way of introducing authenticity to the learning; the conditions under which learning may be made authentic will form much of the basis of the following section.

1.5 How students learn-an introduction to possible teaching models

There is a connection between the types of learning students experience and the pedagogies they are exposed to (Stefano, Stolk, Prince, Chen, & Lord, 2013) and so in order to foster certain types of learning, it is necessary to consider which pedagogies can best facilitate the desired outcomes. The following section will introduce one possible teaching method for providing an authentic learning context for student learning, of both content-specific and transferrable skills (Pinho-Lopes & Macedo, 2014), project-based learning. I intend to introduce a range of perspectives on how best to define the model, with the aim of establishing which are essential and which are peripheral characteristics. Because project-based learning is often associated and/or confused with both problem-based and inquiry learning, the characteristics that separate these methods will also be discussed. Because I argue that all three of these methods may provide authentic leaning environments, 'authentic' will also be defined. Finally, an introduction to the University Technical College (UTC) model that will provide an example of authentic

learning contexts (through a combination of teaching models) will be provided, both as an illustration of authentic learning and as a means of introducing the research context.

1.5.1. Project-based learning

It is both a benefit and a challenge that project-based learning (PBL) is defined in many different ways in different contexts and educational levels (Mills & Treagust, 2003; Thomas, 2000). While the lack of agreement on the subject means there is flexibility for practitioners utilising PBL and researchers making a study of the method, it also creates a dilemma for those attempting to determine what qualifies as PBL and what does not. There are common themes across the definitions though, which make it possible to create a list of essential characteristics which may be seen as the core of project-based learning. These core ideas may also aid in distinguishing PBL from other forms of learning, such as problem-based and inquiry learning (§ 1.5.2 and 1.6, below).

To begin to separate out these core ideas, it is worth referring to the views of both practitioners and researchers. Bender in his 2012 guide for educators for example defines project-based learning as "using authentic, real-world projects, based on a highly motivating and engaging question, task, or problem, to teach students academic content in the context of working cooperatively to solve the problem" (p. 8). This definition includes projects as it must, but specifies that they be authentic, real-world projects. The, to use Bender's term, anchor however can take a variety of forms. The students may be given a direct question, a task, or a problem to solve as the foundation of their project work. This means that the projects may reasonably differ in how open-ended they might be. It also suggests that there may be some crossover with problem-based learning, which will be explored more later. This definition also assumes the intent of the project is to deliver academic content, and that this is done through collaborative work. Some practitioners adopt a more abbreviated definition. Monash University for example, which uses project work in its engineering education programme, considers instruction to be project-based when the "project is the dominant activity" and "students access content when required, but the teacher prepares much of it" (Mills & Treagust, 2003, p. 11).

The implications of this second definition are intriguing. First, the project is central to the unit, or the "dominant activity". There is also the suggestion that interaction with content is

facilitated when necessary for the completion of the project, but may not be the primary aim, and does not have to be initiated by the student. This is in agreement with the perspective of other researchers as well. Prince and Felder (2006) describe the aim of project-based learning as the production of a tangible end product, with the focus being the application of previously acquired knowledge, rather than the acquisition[5] of new knowledge. Prince and Felder also focus on the process and progression of the project: it begins with an assignment, followed by one or more tasks to produce a final product. Their definition also leaves a great deal of flexibility in terms of the assignment, describing task projects, discipline projects, and problem projects, with an increasing level of student autonomy into selection and design, from little to none in task projects to the "nearly complete autonomy" (Prince & Felder, 2006, p.130) in the problem project. The final product is also left unspecified, though they suggest that it may take the form of an oral or written report of the process and outcome.

From the researcher's perspective, Thomas (2000, pp.3-4)'s review of current research into project-based learning identifies a set of criteria that the project itself must display to be considered project-based learning:

-PBL projects are central, not peripheral to the curriculum…

-PBL projects are focused on questions or problems that "drive" students to encounter (and struggle with) the central concepts and principles of a discipline…

-Projects involve students in a constructive investigation…

-Projects are student-driven to some significant degree…

-Projects are realistic, not school-like…

Given that Thomas' intent was a review of current research into PBL, it is unsurprising that his criteria incorporate many of the characteristics presented already. Certainly, the idea of a project central to the curriculum makes sense when describing learning that is, as the name suggests, project-based. It is entirely possible to utilise projects that are peripheral to the curriculum, completed largely at home to enrich classroom instruction or to fill in gaps left by time constraints within the classroom, but these projects are not project-based learning (Bender, 2012).

[5] In this case, the term "acquisition" belongs to the authors of the paper cited. Acquisition suggests a more passive learning experience in which knowledge can be transmitted, which is at odds with my views as a researcher. However, the term was left to faithfully reproduce the thoughts of the cited authors, whose views do have merit.

Craig and Marshall (2019) offer a similar list of criteria to Thomas' (2000) review, separating some elements into separate criteria (italics and numbering from the original):

> (1) Begins with a *driving question* or *challenge* that provides context and drives instruction, (2) Aligns with *significant content* learning goals, (3) Incorporates *21st century skills*, (4) Facilitates *in-depth inquiry* that allows the student to explore the content, (5) Multiple opportunities providing student *choice* and *voice*, (6) Provides multiple opportunities for self-critique and *assessment*, and (8) Results in presenting a final product to a *community audience* (Larmer & Ross, 2009; BIE, 2019) as quoted in Craig & Marshall, 2019))

This updated list has not abandoned any of the elements of the Thomas review, but has rephrased and regrouped them, likely as a result of changes to the prevailing terminology. For example, the student-driven element mentioned by Thomas (2000) is present in the Craig and Marshall (2019) article as 'student choice and voice'. Regardless of the phrasing, neither insists that the project be determined start to finish by the students, but there must be opportunities for students to determine to some extent their projects and their experience with them. Craig and Marshal also do not explicitly require the project to be authentic, but the expectation that the project provide context, and allow the development of 21st century skills, will certainly add an element of authenticity (more on this in §1.7).

The student-driven and realistic (authentic) natures of PBL projects have been touched on in previous studies. A review of literature since the publication of Thomas (2000)'s work, authored by Hasni, Bousadra, Belletête, Benabdallah, and Dumais (2016) allows for a glimpse into the relative frequency of these and other characteristics in PBL for science and technology education. Out of 48 articles reviewed, for example, 27 included authentic problem or question as a criterion. The other common features were: "students engaged in investigations or design activities (23), the project results in students developing a final product (or artefact) (21), collaboration (20), [and] the use of learning technologies (15)". This last is an addition, which may be due to the changing nature of educational technology in general, and the technology available for science education in particular, since the late 1990's and early 2000's. Absent from Hasni et al.'s findings is any mention of the project as central to the curriculum. However, since the very name suggests that

learning in PBL is based on the project, it seems reasonable enough to assume this is a characteristic of projects to constitute PBL.

Based on the sources above, a relatively clear picture of project-based learning may begin to form. The PBL project must, it seems, be authentic, not limiting its applications to the classroom. This is not unique to PBL, as Watts (1994) calls for all science learning to be relevant to student lives and provide real context. It is however a feature that most researchers tend to agree is essential to project-based learning. Next, students must be involved in the investigations or activities. Essentially, students are learning by doing (Baran, Maskan, & Yasar, 2018). While a more traditional project such as those described by Bender (2012) may allow for more passive participation, they are not PBL projects, as they do not engage the students in the investigative elements of the project. The PBL project must also be designed with the intent to produce a final product (Barak & Dori, 2005; Craig & Marshall, 2019; Hasni et al, 2016; Prince & Felder, 2006), though this will vary quite significantly with the discipline.

A collaboration aspect may be desirable, but this eliminates the possibility of individual projects, depending on the definition of collaboration. Because a project undertaken by a single student could still embody all the other characteristics of a PBL project, the collaborative aspect will not constitute a mandatory characteristic of project-based learning. The same is true of the educational technology feature. While Hasni et al. (2016) have shown that this is an important feature for many researchers, accepting educational technology as a mandatory criterion for project-based learning without qualifying that term as well would have little meaning, as this term too is quite broad in meaning. For the purposes of this investigation therefore, project-based learning will be defined as *an authentic, real-world project that is central to the curriculum*[6] *and requires active student involvement in the production of a final product or artefact.* Such projects may involve the use of ICT and may promote collaboration or other skills, and may be used in conjunction with other teaching strategies. One of these, problem-based learning, will be discussed further below.

[6] There have been admittedly a great number of admittedly differing opinions on whether this is a necessary element of PBL or not; while I accept here that the project must be central to the curriculum, I do not seek to narrow that to one definition of centrality, or even one definition of curriculum. This will be further expanded upon when introducing the Challenge Project concept.

1.5.1.a. Project-based learning in action

To fully appreciate project-based learning, it is important also to consider its aims. Just as the projects are not designed to bring students in contact with the same content in every instance, not all PBL projects will necessarily be aimed at helping students develop the same skills. Colley (2008, p. 24-25) chooses to categorise PBL projects based on these aims:

> -Problem solving projects are designed to teach problem-solving and critical-thinking skills.
>
> -Process-skill projects help students acquire science-process skills such as the ability to pose a researchable question, identify and formulate a hypothesis, design and conduct an investigation, collect and analyse data, draw valid conclusions, and document and record findings.
>
> -Design and engineering projects teach design, testing, and production of tools, technology structures, and materials.
>
> -Content or subject-matter projects are designed to teach science concepts, knowledge, facts, history, and the nature of science

There may of course be some overlap between the aims of these projects (Colley, 2008); a project designed to bring student in contact with science content may also help them to develop problem-solving and critical-thinking skills, especially when combined with problem-based learning (below). Likewise, process skills may support critical-thinking skills, and may also teach students the principles of design. Similar to establishing the characteristics of project-based learning, the intent is not to be exclusionary, but to provide a framework for evaluating the projects based on desired outcomes. These categories may prove useful in the evaluation of day-to-day teaching strategies that are utilised in the implementation of project-based learning.

Once the aims of the PBL project are established, it is then for the instructor to decide how to present the project to the learners. While it has been established that the PBL project must be central to the curriculum, the definition of project-based learning includes no mandated teaching methods. Bender (2012, pp. 20-21) suggests that each PBL project will begin with a task, or a "driving question" that is complex, challenging, and authentic. An "anchor", such as a video,

lecture, or other presentation is then provided that gives meaning to the driving question and may also hint at solutions[7] to the question or problem. Students are then set to complete a series of tasks (these may be designed by either the instructor or the students) that allow the students to find a solution (or produce their final product). These tasks can involve planning, researching, experimental design, data gathering, data analysis, and the development of the final product or artefact. In order to ensure that students are at the centre of the learning, the teacher should act as a facilitator for these activities where possible, rather than explicitly defining the tasks. As an additional way to increase student autonomy, a hybrid project/problem-based curriculum, such as that used at the University of Louvain to positive results (Prince & Felder, 2006), may be used to allow students to select and design their PBL projects as a solution to an ill-defined problem (problem-based learning).

Just as no specific instructional methods are dictated by the working definition of project-based learning, neither are there prescriptive time requirements. Projects may vary in terms of duration from a few lessons each (Al-Balushi & Al-Aamri, 2014) to those that can range across an entire course (Mills & Treagust, 2003) depending on the aims, available resources, and the time allocated to the project. Likewise, while the working definition does mandate that the project itself be central to the curriculum, it does not designate a location for the project; project work may take place during scheduled class time, or it may be assigned as an out-of-class enrichment. Such allocations may impact student perceptions of the project; there is some evidence that students who are assigned PBL projects completed primarily at home feel as if they are required to dedicate too much time to their completion (Canelas et al., 2017). A third option, dedicated project time within the school day but outside of regularly scheduled classes, will be seen in the UTC example below (§1.8). In short, even within the working definition of project-based learning, there is a great deal of flexibility in how the project may be structured.

[7] While Bender (2012) suggests that the anchor may hint at solutions, it may be entirely possible, depending on the project, that students be presented with information relating to the project that deliberately does lead them directly to a preferred solution (if one exists), but leaves the project as open-ended as possible.

1.5.2. Problem-based learning

As with project-based learning, there is some disagreement on what characteristics *must* be present in order to constitute problem-based learning. Indeed, Barrows (1986) argues that problem-based learning does not even refer to a single educational method. The collection of methods that may be considered problem-based will share many characteristics, however, and multiple sources have attempted to define them. Many of those engaged in the discussion are those who attempted to define project-based learning above. Prince and Felder (2006, p.128) offer that problem-based learning begins by confronting students with "an open-ended, ill-structured, authentic (real-world) problem" and that students then "work in teams to identify learning needs and develop a viable solution, with instructors acting as facilitators rather than primary sources of information". Already there is some clear crossover with project-based learning, particularly the mention of authentic or real world context. Collaboration, which is a common (though for this research not mandatory) part of project-based learning, is mentioned here as well. The reference to students identifying learning needs and developing (rather than being told or discovering) a solution suggest a high level of student involvement or engagement as well.

It is the first characteristic mentioned by Prince & Felder, "the open-ended, ill-structured…problem" (Prince & Felder, 2006, p. 128), that seems to differentiate problem-based from project-based learning. This is not to state that a project-based unit may not start with an ill-defined problem. Indeed, as will be discussed later, PBL projects may be combined with problem-based learning. It is however merely a potential characteristic of project-based learning, while it is central to the problem-based methods. The history of problem-based learning provides an excellent illustration of this characteristic. McMaster University in Canada, first in Chemistry and more famously in Medicine, made use of problem-based learning as early as the 1960's (De Graaf & Kolmos, 2007). The problems presented may certainly be viewed as real-world, such as those drawn from actual medical cases and introduced with the intent to train general practitioners who looked at the patient, rather than the symptoms. Students are then expected to determine what knowledge they lack, and to then define their own learning goals to solve the problems before them. Because students become the principal investigators, problem-based learning problems are also by their very nature open-ended problems, with outcomes determined by the work of the students, rather than the instructor. This fits both with the description offered by Prince and Felder

above, and with the views of Mills and Treagust (2003), who examine problem-based learning in the context of engineering education.

While medicine and engineering are two fields that produce a wealth of research on problem-based learning, they are by no means the only disciplines to utilise the method. Carrió, Larramona, Baños, and Pérez (2011) integrated problem-based learning into a more traditional Biology course, featuring problems such as "An ecological disaster. A toxic product is dumped in a river and a lot of fish are dead" or "A girl gives birth early" (p.231), with accompanying details sufficient to allow students to begin to form questions and design a method for determining a solution. Once again, the emphasis on the student-driven nature of the design and solution is central to the study, with instructors acting only as facilitators to the students' own learning. With all these characteristics in mind, problem-based learning will therefore be defined as *an instructional method that begins with an ill-structured, open-ended, real-world problem to which students work to design their own solutions.*

1.5.3. A comparison of two methods

As has previously been mentioned, there is a great deal of overlap between project-based and problem-based learning. Both are constructivist (Knobloch, 2003; Kokotsaki, Menzies, & Wiggins, 2016; Mills & Treagust, 2003; Thomas 2000) methods designed to involve students in their own learning. However, there are distinctions that may be made. Problem-based learning is focussed on the acquisition[8] of knowledge, while project-based learning is more focussed on the application of previously existing knowledge (Mills & Treagust, 2003; Perrenet, Bouhuijs, & Smits, 2000; Prince & Felder, 2006). The ill-defined problem that characterises problem-based learning is typically presented in such a way as to require students to identify the knowledge that must be constructed (acquired) to solve the problem (Carrió et al., 2011). While in a hybrid problem/project-based model (the "problem project" mentioned by Colley (2008) and hybrid

[8] Again, the term belongs to the cited author; it is reasonable to assume that the term "construction" might be easily substituted in this definition, as the original article (Perrenet et al., 2000) describes learning as the construction and reconstruction of knowledge.

mentioned by Prince and Felder (2006)) this aim is present in the project as well, it is not a requirement that all PBL projects facilitate the construction of new knowledge.

In terms of structure, the two methods differ in their essentials. As previously stated, the PBL project must be central to the curriculum, while problems may be used for a variety of discrete topics throughout the term (Carrió et al., 2011). For this reason, project-based learning is often seen as a longer term teaching method (Perrenet et al., 2000), with projects ranging from a few weeks (Bender, 2012) to an entire term or semester (Kunberger, 2013; Prince & Felder, 2006). When ill-defined problems are used as a starting point for long-term projects or investigations, they may also be of longer duration, but the literature reviewed here does not establish timelines for problem-based learning to the extent it does for project-based. However, as both methods feature significant variability in time allocation, duration is not a defining characteristic of either model.

The models share a number of similarities as well. Both share a requirement that work be student-driven, though the specific design may vary somewhat depending on the specific problem or project. When designed a certain way, both can be examples of inquiry learning (below) as well (Al-Balushi & Al-Aamri, 2014; Barak & Dori, 2005; Kokotsaki et al., 2016). Perhaps most importantly, both share a requirement that the problem and/or project be authentic[9], allowing students to experience ideas in a real-world setting that can be applicable outside the classroom as well as within.

1.6. Inquiry learning

It has been mentioned previously that both project-based and problem-based learning may constitute inquiry learning under certain circumstances. In order to recognise these circumstances, it is crucial to develop an understanding of what inquiry learning (and the pedagogy that supports it) may be. Perrenet et al. (2000, p. 346) defines learning as "an active process of constructing and reconstructing knowledge", but what separates this broad definition of learning from inquiry learning is a matter of some debate, with most educators being more capable of stating what inquiry is not, rather than what it is (Crawford, 2014). Before considering the methods that constitute inquiry learning, the philosophical underpinnings on inquiry may provide some insight into its

[9] See section 1.7

nature. Inquiry learning is, like problem and project-based learning, constructivist in nature, wherein knowledge is constructed by the learner through "active thinking" (Minner, Levy, & Century, 2010) with the inquirer acting as an "active agent" (Bevins & Price, 2016, p. 18) in their learning. This provides some insight into the essential characteristics of inquiry, as "to learn science from a constructivist philosophy implies direct experience with science as a process of knowledge generation in which prior knowledge is elaborated and changed on the basis of fresh meanings negotiated with peers and teacher" (Watts, 1994, p.51).

This process of knowledge generation is often messy (Bevins & Price, 2016) and without the linear structure commonly presented to students as the scientific method. Attempting to define a particular *structure* to inquiry learning would therefore be far more problematic than useful. A review of the research on the characteristics of inquiry provides some useful insights, however. Much of the literature begins with the acknowledgement of the National Research Council (NRC)'s 2000 (p.25) publication of the following five essential features of classroom inquiry (emphasis reproduced from the original):

> -Learners are engaged by scientific content
> -Learners give priority to **evidence**, which allows them to develop and evaluate explanations that address scientifically oriented questions
> -Learners formulate **explanations** from evidence to address scientifically oriented questions
> -Learners evaluate their explanations in light of alternative explanations, particularly those reflecting scientific understanding
> -Learners communicate and justify their proposed explanations

These characteristics are a useful starting point for, as Minner et al. (2010) point out, each of these features may involve varying degrees of direction or facilitation from the teacher, which means that there is still some flexibility in terms of design. Both Minner et al. (2010) and Bevins and Price (2016) use the above characteristics as a starting point for identifying the aspects (Minner et al., 2010) or dimensions (Bevins & Price, 2016) of scientific inquiry (Table 1.4).

Table 1.3 Aspects or dimensions of scientific inquiry from the literature

Minner et al., 2010 p. 478	Bevins & Price, 2016, p. 18
The presence of science content	Scientific knowledge- includes facts and theories
Student engagement with science content	Evidence-generating and handling procedures- includes data gathering and analysis
Student responsibility for learning, student active thinking, or student motivation within at least one component of instruction- question, design, data, conclusion, or communication	Psychological energy- includes intrinsic and extrinsic motivation

The mention of science content or knowledge of content is not surprising, particularly if it is assumed that the goal of inquiry is to increase student knowledge. The NRC (2000) guidelines suggest student engagement by content as well. While Minner et al. list student engagement as a separate aspect, it is clear that the two are linked; without scientific content, there can be no engagement with it. While Minner et al. are more explicit in emphasising student responsibility for data gathering and design, it is implicit in the work of Bevins and Price as well. The evidence-gathering and handling procedures, tied in with the psychological energy (Table 1.43would also lead to students taking control of their learning. What is important to note is that these aspects do not lead to one another in a linear fashion, but are simply related to one another as pieces of scientific inquiry.

In many ways, it is easy to see how practitioners and researchers alike might equate scientific inquiry and inquiry learning with the scientific method. However, as Campanile, Lederman, and Kampourakis (2015) state, there is no single series of steps that can be called the scientific method, and results obtained by one scientist or group may not be the same results of another. Certain elements, such as the generation of questions, design of procedures to gather evidence, analysis of evidence, and communication of results, appear frequently throughout the literature, but they do not need to occur in sequence, nor is there any clear dictate that these be student-driven in all cases. Bevins and Price (2016 p.20), along with many others, view inquiry as a spectrum, with structured, guided, and open inquiry as classifications dependent on the degree

of student autonomy in each skill area. Within this spectrum may fit many different models of learning, including problem-based, project-based, or a combination of the two.

1.7. A note on authentic learning

The terms 'authentic learning' or 'real world' learning are used throughout this literature review, and no attempt to define these has yet been made. This is not because this is not an important consideration, but rather because it is of such importance that it merited greater consideration than other terms which could be easily clarified in a footnote. Defining authentic learning presents many of the same challenges as defining project-based, problem-based, or inquiry learning above, in that there is some disagreement amongst researchers as to what precisely constitutes authentic learning. Beier et al. (2019) focus on a narrow interpretation of Thomas' (2000) definition of an authentic project, considering only those that are client or employer-driven. Others use the term more broadly; Thomas (2013) for example does not specify elements which make learning authentic, focussing instead on the outcomes. For her, authentic learning is that which imbues students with the thinking skills necessary for most pathways into a 21st century workforce. Many of the outcomes she mentions have significant overlap with the outcomes of Fink (2013)'s significant learning, which is not surprising considering both focus on how to take learning beyond the classroom.

How then is learning made authentic, to allow for the development of these skills that are applicable beyond the classroom? Knobloch (2003) places a great deal of emphasis on the context of the learning; learning taking place in real-world contexts is more likely to carry over to applications in the real world. Much of the literature agrees that it is the teaching method as much as the specific topic that enables the learning to be authentic; problem-based (Carvalho, 2016) as well as project-based and inquiry-based (Thomas 2013) are both considered methods that allow for authentic learning to take place. This is not to say that the topic of focus of these teaching methods must not also contribute to authenticity. Work that merely borrows from the real world to create a visual (such as word problems in mathematics concerning the addition or subtraction of marbles or apples) does not necessarily trigger this type of learning, and is therefore not automatically assumed to be authentic. At the heart of the classification lies the applicability of the

learning for the future, and it is this criterion that will supersede all others in determining if authentic learning has indeed taken place.

It is little surprising that project-based learning and authentic learning are considered together; while it is certainly possible for learning to be authentic without being PBL, the reverse is not true. A project-based learning project must be authentic in order to be considered PBL. This has roots in the origins of the PBL project, which developed long before modern pedagogical notions, but to achieve similar ends. From the model's origin in the 16th century "*progetti*" held at the architectural academies of Rome (Knoll, 1997), the PBL project has been used to equip the learner with the skills necessary to succeed in life after the conclusion of formal education. These early projects were purely hypothetical; an exercise in imagination. In these cases, the tangible artefact was the design rather than the structure it planned for. In such a way were students able to apply their skills (and knowledge) directly to the sort of task they might face upon graduation.

Projects were also brought in to increase the authenticity of learning in other subjects, most notably engineering. The University of Illinois Champaign-Urbana (then the Illinois Industrial University) school of Mechanical Engineering was from its founding based on the idea that practical work, particularly projects, make up an essential component of the curriculum (Illinois Industrial University, 1868). This was seen as a way to create industry-ready graduates in the field of engineering because they allow the development of those transferrable skills (§1.4.2) that help students make the transition from learners to practitioners. Learning by doing is an essential element here as well, as when students are actively participating in these projects, it is likely the authenticity of the project is more apparent to them as well.

Authenticity remains a key component of project-based learning across disciplines. Vogler et al. (2018) made authentic collaboration a cornerstone of their project, defining authenticity as a realistic context where the skills applied to complete the project were the same ones that would be used outside the classroom (p. 458), such as communicating across disciplines (in this instance, computer science, graphic design, and hotel/restaurant administration), and negotiating with those other disciplines to work within constraints similar to client demands. The students' perceptions of the skills they needed in terms of collaboration and teamwork mirrored a typical client and contractor viewpoint (p. 466) seen in industry as well. In this sense, by doing a project related to their chosen industry, the students were developing not only skills but also attitudes that they will carry with them beyond the classroom.

1.8. The UTC model

In England, the growing demand for sixth form leavers with transferrable 21st century skills can be seen in the development of the University Technical College (UTC) group of 49[10] schools, each of which includes a project component in its curriculum. These are generally determined by the needs of the region, as employers and local universities collaborate and back the projects with the intent of helping students to develop both an understanding of the core concepts underlying the project and relevant technical skills that could then be taken into the workplace. In the Cambridge UTC[11] (CAST) for example, students spend one to one-and-a-half days every week engaged in a challenge project supported by local engineering firms or biomedical research centres. The projects often (but not always) link with the current core content, and allow for the application of ideas previously covered in classes (UTC, 2016). These Challenge Projects have included, at various age levels, hydroelectric dam design, enzymology, computer coding, and lab animal welfare projects. Students in years 9 and 10 participate in the same project across the year group, and students in years 12 and 13 select a project from a set list of choices. Students work in groups to complete their project and present their findings to their peers, teachers, and often members of local industry. This type of programme, with a large number of possible learning objectives attached to the projects, may provide a useful setting for research into the ways that project learning can impact the various types of learning discussed previously.

UTC's are a relatively new type of secondary school, with the first UTC, JCB Academy, opening in 2011 (Long & Bolton, 2017). As such, any evaluation of the model has been conducted with relatively few years' worth of data. Across the nation standardised assessment marks are quite low, with the 28 UTC's included in GCSE data reporting a 51% A*-C pass rate

[10] Figure is correct as of time of publication; the number has fluctuated from year to year
[11] The Cambridge UTC has undergone academisation and has since been rebranded at Cambridge Academy for Science and Technology, or CAST

compared to a 64% national state school average in 2015/2016 (Long & Bolton, 2017). It is worth noting, and indeed it is noted in the report, that the majority of these pupils spent the bulk of their secondary years in other schools, and therefore few conclusions can as yet be drawn on the impact of the UTC model on academic performance. Additionally, there are further measures of success that may be considered in such a model, including placement in apprenticeships, ease of entry into local industry, and perception of career readiness which are not measured by national testing.

In terms of these other successes, students at UTCs are well aware that they are acquiring skills that will benefit them as they head on to work, apprenticeships, or university. As a result, students also felt generally positive, reporting that they believed their motivation, engagement, and confidence were all enhanced by the UTC model (McCrone et al., 2019). McCrone et al. continue their report by examining three individual UTCs, in Birmingham, Liverpool, and Reading. Each had a different approach to its projects, but all three had high employer engagement in the design and implementation of the projects, which was reflected in the level to which students felt prepared for entry into industry. Students also felt their projects helped them prepare for academic qualifications in a way their peers could not, with one student remarking that "without doing PBL, you'd know the word for these bits of equipment but you'd never get to use them" (p. 24). The UTC that forms the research context for this study incorporates much of the same ethos as the model UTC's presented in McCrone et al.'s report, and indeed much of the learning evidenced in the research participants is similar to the outcomes seen in these schools.

Because one of the core components of the UTC model is the project element, it is worth considering how the projects fit within the characteristics of PBL discussed above. While each school sets its own individual standards for their projects, employer connections which form a large part of the UTC identity might reasonably be seen as providing authenticity, connecting the projects to the real world. This may be the only universal characteristic of the UTC project model; each school then establishes the structure of their own projects. For this reason, and because it forms the research context for the case studies presented in Chapters 3-6, the CAST Challenge model will be considered here. The Challenge projects, as discussed with school staff prior to the collection of data, are designed to be longer-term projects with as much employer input as possible, so as to make the projects 'real' to the students.

The Challenge projects also feature a particular aim, a product or idea that forms a target for the students as they work through the project activities. Some of these activities are prescribed, but even the most structured project allows for students to make some choice as to their next steps within their projects. The Water Monitoring Project, which will be featured in Hamish's narrative, is a prime example of this. While this (and other) projects may be viewed by the students as supporting very little *in-depth inquiry*, the open-ended nature of certain tasks allowed for some opportunities even in a project perceived as less open-ended. Certainly, Craig and Marshall's point about self-assessment could be seen in all observed projects, as the students were quite willing and able to evaluate not only the nature of the projects, but their ability to complete them to certain standards.

The area where perhaps there may seem to be the least alignment is in terms of the centrality to the curriculum (Thomas, 2000), the ways in which *significant content* learning goals (Craig & Marshall, 2019) are met. As will be seen in the comparison between the Challenge projects observed at CAST (§7.2), there is a great deal of variability in terms of the aims of the projects, and their alignment with current course content. Indeed, because students in years 12 and 13 are free to select one of three projects, each with a different content area focus, students may end up in projects with no direct ties to their A Level or BTEC courses at all. To assume that projects must have direct ties to a particular strand of the curriculum may be to unnecessarily narrow the definition of centrality, however. CAST Challenge projects are, by design, meant to instil not only content knowledge but the *skills* expected of a 21st century learner. This is a key focus of the UTC model in general, and the CAST model in particular has been developed around the idea of preparing students to leave as scientists, rather than as students with science knowledge.

In this way, the Challenge projects fill the core of the CAST curriculum, much in the same way that Theory of Knowledge (TOK), the Extended Essay (EE) and creativity, action, and service (CAS) make up the core of the International Baccalaureate Diploma Programme with the aim to "broaden students' educational experience and challenge them to apply their knowledge and skills" (IBO, 2019). The projects at UTC seek to build upon the content taught in lessons, and allow students a chance to interact with it more-or-less on their own terms, and to make use of their knowledge as they build the skills necessary upon their leaving the college, whether that be to apprenticeships, jobs, or university courses. While the Challenge projects may not tie

directly into the content aims of an individual course, they are still a central and critical component of the well-rounded curriculum that CAST seeks to provide for its students.

1.9. Intended outcomes

Through a review of the literature, it has I hope become evident that PBL, in particular project-based learning, is a method that *can* be utilised to help students meet a variety of learning goals. It should also be evident that these learning goals may be met in different ways. If we accept that learning means creating the potential for change, we must also accept that not all learning that has occurred will be immediately discernible. Some evidence of learning can be collected when changes to the learners' processes or attitudes are seen during the projects, while others are most evident from direct conversation with the students. Some changes may not have been directly observed at all, but the potential is there. While only those that have been made explicit either by word or by deed are documented in the following chapters, I feel quite strongly that at some point in this work it is recognised that the projects I observed could have had an impact on the behaviours of the students in future projects as well.

It should also be noted now that not all students will learn the same things, even when engaged in the same project. This is due not only to the group nature of the projects (which often allow students to focus on areas of interest), but on the constructivist underpinnings of project-based learning (Menzies, Hewitt, Kokotsaki, Collyer, & Wiggins, 2016). Constructivism holds that, in essence, students are engaged in constructing their own knowledge that is based on their individual experiences, and so any teaching method based on these principles should allow for individual learning. There will be points in Chapters 3-6, which focus on the narratives of three individual students, where the learning the participants are experiencing is dissimilar to any of the other cases; this is a natural and expected part of a constructivist teaching method.

There will also be points in which it is difficult to characterise whether the students are truly developing new skills or applying pre-existing ones; this too is expected in a model that is dependent on the application of prior knowledge (Prince & Felder, 2006). However, in instances where this is occurring, it is the student being motivated by novel circumstances to apply existing knowledge and skills in new situations that allows this application to be considered learning.

Where this occurs, careful consideration is given to whether or not this is the case, and to whether or not this constitutes learning. One instance that is likely is the overlap of domains previously unconnected to one another as a means to make learning significant (Fink, 2013). That said, not all application in project-based learning is evidence of change; § 2.7 will focus on the process by which student actions were analysed, and thus whether particular outcomes could be considered learning or not.

1.10. The research questions

Based on this review of the existing literature, two research questions have emerged:

1) How do students learn while engaged in project-based learning in secondary science?
2) What effects do different aspects of project learning have on the learning taking place?

The remaining chapters will seek to answer these two questions through the narratives of three participants based at the Cambridge Academy for Science and Technology. These two questions accept the definitions of learning and of project-based learning determined through this review of the existing literature, as well as the guiding principles of constructivism (more on this in chapter 2). They also serve to guide the design and implementation of the research methods, not only for observation and data collection, but for the analysis as well.

CHAPTER 2- Methodology

2.1. The researcher

It is my personal belief that it is impossible for a researcher to remove all traces of self from one's research. It does not follow that this is detrimental to the research, but it is essential to identify and address as many assumptions regarding the research as possible so as to ensure a valid and reliable study. To introduce the origin of my assumptions, I offer a brief introduction of myself as a researcher. My academic background is in the natural sciences, specifically biology and chemistry. Both of these fields believe in the use of measurement and observation to collect data from which generalisable conclusions may be drawn. My secondary area of study was in psychology, with a focus on animal behaviour. The major assumption made during practical work in this field was that observable behaviours are the primary means by which to identify learning. It also required a willingness to accept observer interpretation as a valid tool in the research process.

I progressed into teaching before receiving any formal training in education, and so my earliest years of practice were informed by my background in the natural sciences alone. This in turn influenced my Masters work in Education, which focussed on the use of a reward system for eliciting participatory behaviours in students. In subsequent years as a teacher, most of my instruction focussed likewise on developing certain measurable outcomes and behaviours. The results of this background are the following assumptions:

-Student behaviours may be influenced by the teaching method in use
-Student behaviour can be observed and classified to a certain extent
-These behaviours may provide some indication of learning
-Different students may display similar behaviours at similar points in their learning processes

Each of these assumptions will be addressed in greater detail where relevant. However, I feel it important to note that observable behaviours such as verbalisations, inscriptions, or actions will not be viewed as perfect representations of concept formation or other learning. Perfect representation is surely impossible. However, my assumption is that this data can provide a

useful indication of the conceptual frameworks being built by the students. I am also assuming that behaviours can be organised into certain categories by the researcher, though these categories and any resulting subcategories may be subject to modification as a result of monitoring. Finally, I also acknowledge that these categories and codes may differ from those that may have been assigned by another researcher, and thus the narrative that is formed here is dependent not only on the data, but also on my interpretation of it. This will be explored more thoroughly in the discussion of the research paradigm below.

2.2 Ontology

Before a methodology can be considered and selected, certain beliefs and assumptions regarding the nature of reality and knowledge must be established. When it comes to reality, this presents an interesting challenge, particularly in the social sciences. Research of the type I am undertaking must rely not only on natural science but also on the social context in which learning is occurring and any impacts this may have. This may lead to a potential discrepancy in relation to ontological beliefs; the assumptions made about reality in the natural sciences may differ from those in the social sciences, due to the nature of the most common ontological stances. The ontological spectrum is bookended by two stances: relativism and realism. Generally speaking, relativism is the belief that realities are relative social constructs, and that no single reality exists. Realism, on the other hand, posits a single, knowable reality. As these may be considered two extremes, it is perhaps unsurprising that both are potentially problematic in terms of this study. Conversely, they also both have appeal in certain areas, making ontology a complex issue.

Relativism places an emphasis on the social construction of reality (Ritchie & Lewis, 2003). When considering student conceptual frameworks, this ontology is an attractive one. It is being assumed that the framework in fact exists, in the mind of the student, and can be added to or modified over time. The framework will follow certain rules and possess a certain structure, yet is constructed socially and within a given context (Crotty, 1998). Students' conceptual frameworks will be unique to each individual, because their experiences have (presumably) been likewise unique, and these guide the development of the conceptual framework. Relativism may hold a certain appeal for those whose focus is on the learner's construction of their own knowledge structures, but becomes problematic when that learning is occurring in the natural

sciences. A belief that reality does not exist beyond our perception of it would contradict many of the assumptions made in the science classroom about the nature of objectivity and by extension objective research. If I were to choose to assume that there is an objective truth for students to learn , realism would seem to present a more compatible viewpoint.

Realism suggests that a single, knowable reality exists independent of the researcher or observer (Yin, 2014). Realism also posits that through direct contact with phenomena, concrete and unquestionable knowledge of them can be gained (Hammersley, 1992) which would suggest that each learner's goal is to know with certainty the objective truths of their project. In many ways, this is consistent with the emphasis on repeatability in the natural sciences, supported by the scientific method (Maturana, 1990). The goal of science may be considered to be not only to uncover meaningful scientific knowledge, but to do so in a way that anyone, regardless of personal identity, would be able to produce identical results, given the same conditions and resources. Realism suggests that this is exactly the way reality works; our individual perceptions do not change reality, nor are they necessary for reality to exist. For some natural scientists, this focus on objectivity and an independent reality may seem to make realism the ideal ontological perspective.

While realism works well to account for the nature of physical things, the assertion that contact with reality leads to unquestionable knowledge of it is problematic in a modern educational setting. In addition, while realism has its adherents in the scientific community others, such as Maturana (1990), argue that: "Science is a human activity. Therefore, whatever we scientists do as we do science has validity and meaning, as any other human activity does, only in the context of human coexistence in which it arises" (p. 16) and that "…scientific explanations and scientific statements do not refer to an independent reality and do not depend to do so, such notions do not apply in the domain of science" (p. 23). Because one of the jobs of a science teacher is (one might argue) to help students think like scientists, an ontology that ignores entirely the impact of the observer seems inappropriate.

It would appear then that neither pure relativism nor pure realism are compatible with the underlying philosophies of science and science education. Fortunately, Hammersley suggests an alternative in the form of subtle realism which presents more of a compromise between these two stances:

> …subtle realism shares with scepticism and relativism a recognition that all knowledge is based on assumptions and purposes and is a human construction, but it rejects these positions' abandonment of the regulative idea of independent and knowable phenomena. Perhaps most important of all, subtle realism is distinct from both naïve realism and relativism in its rejection of the notion that knowledge must be defined as beliefs whose validity is known with certainty (1992, p. 52)

This subtle realism offers an alternative that is neither pure realism nor relativism, which allows the research to be framed in such a way as to account for the idea of universal truths without dismissing the power of the individual experience or understanding. It acknowledges that the researcher cannot have absolute certainty of their findings, as different methods will produce different pictures of the subjects of the research (Duncan & Nichol, 2004). While there have been criticisms of the stance, particularly that it is 'ontologically shy' (Banfield, 2004;), its proponents have recognised its utility in research in cases where there is a need for flexibility.

2.3. Epistemology

The difficulty in choosing an appropriate epistemology lies in the differences in the way the social and natural sciences are approached. It is not critical that the epistemological stance adopted be compatible with the teaching methods under investigation, but my personal commitment to project-based learning will certainly have an impact on my research, and therefore an epistemological stance that aligns not only with my beliefs as a researcher, but with the underlying principles of project-based learning would be ideal, although certainly not necessary. Because this work is examining learning within a science-based project, objectivism is the first stance I considered. After all, one of the central ideas of objectivism is, unsurprisingly, that reality is objective. This may appear on the surface to resemble the guiding ideals of many science classrooms, especially when one considers the scientific method, which tends to suggest that knowledge is gained through objective experimentation and observation. Objectivism however rejects the notion that the meaning of an artefact is influenced by context or consciousness, ideas which are quite important to project-based learning (PBL). Also of concern is the belief that knowledge is transmitted rather than created in the mind, which is also

contrary to the guiding principles of many student-centred teaching strategies, including PBL. Because of these two discrepancies, objectivism as an epistemology must be rejected for this study.

When looking for an epistemology that is compatible with my own beliefs and the principles of project-based learning, constructionism seems to be the ideal choice. Constructionism is based in the belief that "telling children how scientists do science does not necessarily lead to far-reaching change in how children do science; indeed, it cannot, as long as the school curriculum is based on verbally-expressed formal knowledge" (Papert, 1991, pp. 10-11). In the same manner in which PBL asserts that individual student experiences will construct a final product (be it a report, a presentation, a poster, or just a new body of knowledge) through interaction with the project, so too does constructionism rely on the sensory interaction with reality to construct meaning. Constructionism also holds that, while the individual may construct meaning internally, it is not in isolation, as social influence and context help to form knowledge and meaning (Crotty, 1998). While constructionism is highly compatible with the teaching methods being observed in this research, the emphasis on highly situated learning and the suggestion that learning only through the creation of a public artefact (Ackermann, 2001) creates a limitation in terms of the assumptions that can be made in this investigation. Because one of the questions being considered concerns which aspects of project-based learning do have an impact on conceptual development, it would not be appropriate to begin with the assumption that only in certain situations does this occur. While it is possible that this might be the case, it cannot be established at this point, and therefore constructionism as an epistemology cannot be accepted at this time.

Constructionism shares its core beliefs with another epistemology which holds many of the same assumptions about learning, however. Constructivism, as influenced by the works of Piaget and Vygotsky among others, also suggests that learners are internally constructing meaning as a result of exposure to a stimulus of some kind. Constructivism rejects the transmission model of education in favour of experiences that initiate individual learning and conceptual development (Ackermann, 2001). It is the belief of constructivists that each individual learner constructs meaning for themselves based not only on their current experiences but those that they have had in the past (Fensham, Gunstone, & White, 1994) and that there must be a reconciliation between old ideas and the new to allow students to form new knowledge.

Constructivism does not limit its assumptions about learning to the production of artefacts, or "making" as constructionism does[12], but does still hold that it is through experiences that learning happens. Because of this more flexible assumption in terms of how learning occurs, and its compatibility with project-based learning (Kokotsaki et al., 2016; Menzies et al., 2016; Thomas, 2000), constructivism will be adopted as the epistemological stance for this research project.

2.4. Theoretical framework

The selection of a research methodology involves not only the considerations already discussed, but also the beliefs of the researcher regarding their role in the investigation, as well as the goals of the investigation as a whole. These constitute a philosophical stance that helps to shape the research methodology. These frameworks need to be compatible with the chosen epistemology. Positivism, for example, relates to the objectivist stance discussed above. Positivists tend to think empirically, placing importance on what can be observed, and little consideration is given to speculation (Crotty, 1998). While this objective stance may be of value in certain scientific contexts, and certainly may be considered by some behaviourists, I do not consider it to be an appropriate framework for investigating these research questions as it has already been established that *readily* observable behaviours are not the sole indicators of learning.

In terms of both the compatibility with constructivism and my own beliefs about the role of the researcher in this investigation, interpretivism is the natural and logical choice. In contrast to positivism, interpretivism, as the name suggests, allows and even requires interpretation of the data being collected (Crotty, 1998). The researcher is a participant in that they are adding their interpretations of the data, and thus interpretivism is a highly subjective perspective by design (Bryman, 2012). If as the researcher I am making the assumption that the knowledge of the learner is internally constructed rather than transmitted, it is logical to assume this is true of my knowledge as a researcher as well. The choice of interpretivism acknowledges that not only

[12] There are some researchers who do not distinguish between constructionism and constructivism, such as Bryman (2012). Indeed, there are sufficient overlaps that a broader definition of either may accurately fit the other. However, it is constructivism as is outlined both here and elsewhere that forms the epistemological foundation of this research

does the researcher have an impact on the study subject, but that this is a natural part of the research process. Given my background in the classroom and the assumptions that arise from this, a paradigm that acknowledges and accepts these is essential. I will therefore be moving forward with interpretivism as the theoretical framework through which I will be designing and conducting this research.

2.5. Methodology-case study

The following section will outline the justification for and implementation of the selected research method, the case study. There is no firm consensus on the exact nature of the case study (Stake, 1995), but in general it is a method that, as the name suggests, studies in depth a single case or, in some instances, cases. The case study is not unique to educational research; the problem-based learning model above often makes use of case studies from medicine, engineering, law, or other relevant subjects. The case study may take either a qualitative or quantitative approach, and this is often determined by the nature of the case. In instances where the case is an individual, it is more likely data will be qualitative in nature, where a case study of a nation or even large network (such as a school district) might well include more quantitative components. The essential characteristic in my view, which led to its selection here, is the richness of the narrative that arises from the in-depth study of the individual case. The specific methods by which this narrative is collected, analysed, and presented will be laid out below.

2.5.1. Relation to research question

Before beginning the description of the research methods, it is worth revisiting the research questions:

1) How do students learn while engaged in project-based learning in secondary science?
2) What effects do different aspects of project learning have on the learning taking place?

In the first instance, it is my intent to map out how changes to the knowledge, skills, or behaviour of the students occur throughout a PBL project. The methods for doing so will be

elaborated upon further on in this thesis. The second question may in fact be considered a subset of the first question. Domin (2007) found that "students felt more cognitively engaged" (p. 146) when they were working in a more open-ended, problem-based environment, and perceived that their cognitive development differed based on the learning style. What my study aims to achieve is to identify in greater detail how different aspects lead to different types of learning, or at least in the view of the student.

The first question is very clearly a "how" question (Thomas, 2016 & Yin, 2014), seeking to develop an in-depth understanding of the learning process (Creswell, 2013)-an understanding of understanding, in a way. The second is in many ways also a "how" question, though there is an added dimension requiring an attempt at matching different aspects of the PBL project with types of learning. The intent is not to make a judgement of PBL in comparison to other methods; if it were, a comparative research design might be more appropriate (Thomas, 2016). The aim is not to definitively prove causality, nor is this research hoping to provide a generalisable answer to the question "does learning occur during a PBL unit", because one of the assumptions being made is that some form of learning will occur at some point during the unit. The purpose of this research is to study in-depth the nature of this development through the use of PBL strategies and thus the case study methodology is most appropriate (Thomas, 2016, & Yin, 2014).

2.5.2. Relation to the research paradigm

While the research questions were primarily the reason that a case study method was chosen, it is also important that there be compatibility with the research paradigm as well. The case study is one research method in line with the constructivist stance. The case study provides an in-depth look at a particular case (or cases) and is concerned with, in this instance, the way students learn in a particular setting. It does not make the assertion that any student in any school would learn in the same way or even at all. Sweeping generalisations are as foreign to the case study as they are to the constructivist stance. This is also in line with the identified ontological perspective. The subtle realism described by Hammersley (1992) above allows that "there can be multiple, non-contradictory and valid descriptions and explanations of the same phenomenon", which could apply not only to student testimony relating to their experiences in their projects, but also provides support for the interpretivist philosophy of the research.

Certain assumptions of mine will certainly have an impact, regardless of my intent to separate myself from them. Interpretivism suggests that, as the researcher, it is impossible to completely separate myself from the research and its findings (Ritchie & Lewis, 2003), and this will mean that my findings, no matter how faithful to the data, will differ from the findings of another researcher. This is not incompatible with rigorous case study design, so long as the design acknowledges and accounts for this at each stage of the research process. Indeed, because the case study requires diverse sources of data, these assumptions and interpretations can be checked against a range of student-generated data for accuracy and validity, with the final product being a comprehensive image of the students' learning and the process by which it occurs.

2.5.3 Defining the case

A well-defined case study must first of all be the study of a well-defined case or, in this instance, cases. This begins by deciding upon and justifying the selection criteria for the cases. Thomas (2016) suggests three types of case: key case, outlier case, and local knowledge case. Each of these points to a particular rationale for the selection of a particular case. In the instance of a key case, it is most appropriate to select for study a case that is exemplary in some way. Thomas cites Hurricane Katrina as an example. While similar in many ways to other hurricanes, its size and impact make it of particular interest to researchers. The outlier case will take this a bit further, and be selected by the very virtue that it is not like other cases, and deviates significantly from the norm in some way. This type of case will most likely deviate in one particular area, but may share many other characteristics with otherwise similar cases. The final type of case described by Thomas (2016) is the local knowledge case, where the case is selected because it is already well-known to the researcher, and access to the case is likely more readily available.

Part of defining the case is in determining criteria for inclusion within the case (where a case has multiple subjects[13]) or as the case (in single participant/entity studies) . I selected for my cases three students each engaged in one of a series of projects based around one or more of

[13] For example, a case study concerning mortality rates in Finnish infants would need to ensure that any participants were in fact Finnish infants (or their parents) and do so by defining "Finnish" and "infant"

the natural sciences. These students were involved in two different projects; two were in a Computer Science based project, and the third was in a Water Monitoring project. The participants were selected based on interest in participation, and the project allocation was a combination of student academic interest and availability. Given that I am not a current teacher, parent, or student currently in a secondary school, these cases were not those of local knowledge. The issue of outlier cases is more complex, however. Certainly in order to be able to investigate changes to knowledge and skills in PBL units, the selected programme, as part of the research context, must have units developed to be based on meaningful and authentic projects. While PBL is growing in popularity in both the US (Ellison & Freedberg, 2015) and the UK (Abrams, 2017), it is by no means the prevalent teaching model in schools. A school or programme that chooses to base the curriculum on PBL may therefore indeed be seen as unique in terms of pedagogy, meaning the research context at least must be considered an outlier. Within the context of the school, however, the cases were chosen to be representative of the context. There is a risk that there existed a form of selection bias, as students willing to invest the time in such a project may have been more naturally inclined towards the sciences in particular, or in academic pursuits in general. Each of the cases can be seen as a key case then, but with the understanding that they may deviate from the general student population in some ways, beyond the extent to which any student is a unique learner.

In selecting the appropriate population from which to solicit volunteers, additional concerns arose. While the larger context of the school may be limited by the relative rarity of such a programme, it might be expected that, within the school, more options are available. Within the school context, different projects were going on simultaneously, and different year groups had very different levels of autonomy in their projects. For this reason, students in Year 10 were not offered a chance to participate[14], as projects will typically be more guided, as suggested by pre-pilot discussions with the school site. Students in Years 11 and 13 were not going to be as readily available for follow-up interviews if needed, and stopped project work earlier to prepare for their examinations. Choosing to work with Year 12 solved both problems, and early work suggests this age group was quite open to participating in research.

[14] One year 10 project was observed, and a student by the pseudonym Hart gave a few interviews relating to his experience, but these were to provide more insight into the Challenge model, not as an additional case

While ideally the students selected would represent a range of abilities and interests, an investigation of this nature was always going to be dependent on the willingness of the participants. While initially over a dozen showed interest, less than half that number returned all the consent forms or replied to indicate continued interest[15]. This left a much smaller pool of candidates from which to select participants, though by accident rather than design, those that did indicate continued availability had a range of interests and were enrolled in a variety of courses (two in A Levels, one in BTEC). More detail about each of the participants can be found in the introduction to their individual chapters. The school selected, as is common amongst UTC's across the country, has a male to female ratio that is much larger than the national average for this age group (Long & Bolton, 2017), so it is surprising that more female students than males showed interest. In the end, one male and two female students agreed to participate in the research.

2.6. Data collection (methods)

Data in this study took two primary forms: lesson-focussed (observation), and student-focussed (interviews). These were complemented with informal teacher interviews, and a single formal interview with the programme director. However, the focus of this study was on how students learn, and which elements of the projects inspire that learning, so it is I suppose unsurprising that the bulk of the data is in the form of interviews and observations. School-focussed data, such as policy documents, curricular documents, and the official prospectus, provided background on the research context, but had little direct impact on the collection of the primary data. Initially, it had been my intention to collect and then analyse each type of data independently and then connect the two at the end, with the student-focussed data primarily providing insight into research question one, and the lesson-focussed data providing answers to research question two. What I discovered early on was that this method was flawed, in that the interaction between lesson and learner was constant, and so the two primary data sources complemented and informed each other for the majority of the study.

[15] Several students returned forms but did not reply to confirmation emails; several others replied to recruitment emails but did not return forms. Only the three student selected did both

2.6.1. Lesson-focussed sources of data

The two main sources of lesson-centred data were the project briefs (which included rough lesson plans) and the observations. While lesson plans (and, presumably, project briefs) may contain an idealised version of lessons to be taught which may introduce a certain level of bias (Yin, 2014), they are also a relatively stable and objective form of data that provides at least an indication of what will be covered in the unit and when. Changes to these plans were noted where relevant, though little of this proved necessary. These plans were not particularly detailed, but were in the case of the Water Management Project (WMP) supported by additional documents provided to the students via the school's cloud-based storage, to which I was granted access. This meant access to the same resources the students had access to, before or during the lesson.

Prior to the unit of instruction, informal interviews took place with the UTC teacher in charge of each project. The main purpose of this interview was to receive clarification on any areas of the unit lesson plans which may have been unclear to the researcher. Though in both cases the objectives laid out prior to the project shifted somewhat, it did allow me to approach the observations more aware of what objectives the teachers at least had for the students. There was initially some concern that such an interview may have an impact on the project objectives or individual lesson plans (Ritchie, 2003), but none of the changes to the initial plan could reasonably be seen to have been influenced by this discussion, which could have compromised the naturalistic character of the case study (Taber, 2013). The other purpose of the interviews, to understand better the concepts the students may have been previously exposed to in lessons, was also successful. All of these elements contributed to the development of a more logical structure for the primary data collection.

The classroom observations were conducted by myself in the capacity of researcher, and focussed on the students that constitute the selected cases, though additional students were useful in providing a contrast in some instances, particularly when Hannah (one of the participants) would mention her work with another group. This will be further explored in §2.7. While audio or video recording would certainly have produced the most faithful reproduction of what can be captured by such means, the setup of the Challenge projects made this difficult logistically, as students were frequently not only moving from one side of the room to the other but to

completely separate rooms. Another concern was the impact such devices would have on student participation, particularly those of peers who are not part of the study yet interact with the participants. One student who frequently collaborated with one of the participants had explicitly opted out of being recorded, for example. A running list of notes was therefore taken in each session as needed, and key events identified and confirmed during the student interviews where necessary.

In terms of my presence during these observations, I chose to establish in each of the classrooms a single location from which to be based, and then to move about as necessary. By choosing to situate the computer in a central location and the walking around the classroom as students are working, I was able to observe a wider range of student behaviours and conversations while also still being able to note down anything while the information was still fresh. Experience during the pilot study suggested that students were unconcerned by notetaking in the room, and there was no clear change in behaviour when I was typing, so this was determined to be an ideal way to make faithful recordings of each lesson without compromising the behaviour of any student, participant or not. Observations were held once per week, during the time in which students were working on the Challenge Projects.

The typical time frame for these projects was from 9:35am to 3:45pm, with a 20-minute break in the morning and a 50-minute break for lunch. Typically, each project had an introductory session before the break, and then students were actively working on their projects after the break and then after their lunches. In the introductory session, I would check in on the Computer Science (CS) project before spending the majority of the pre-break period with the Water Management project (WMP). This was due to the greater variety between sessions in the WMP. The remaining time was divided based on the activities of each project on a given day, and often did not follow a set time frame. However, every effort was made to equitably divide time between the two projects, and to be present for critical periods of each project to observe anything of considerable note.

Determining what was noteworthy in these circumstances presented some challenge. Piloting had suggested that actions directly related to the task outcome (such as one pilot participant deciding to run an iodine test to determine if a substance in his test tube was starch) made for useful prompts in the follow-up interviews. Anderson et al. (2001)'s and Fink (2013)'s taxonomies also provided useful suggestions of what to look for. The final inspiration was the

pre-session interviews, where the participants would outline their own goals. Behaviours relating to those goals were therefore looked for with care. As the first few weeks passed, behaviours outside the norm for the participants also became noticeable, and then frequently were noted as well.

The primary logistical issue that emerged as part of the collection of this data was that the two projects ran simultaneously. While the solution to this would initially have been to revisit the idea of recording devices, the nature of the WMP meant that it was impractical, and the participant consent issues in the CS project made it unethical. Therefore, the compromise reached here was to rotate between projects at intervals determined to be logical based on each project's structure for the day, and to consult with each instructor both before and after each day's lessons to ensure nothing of import was missed.

The interview protocol, described below, also served to reduce the impact of missing portions of each project; by aiming to interview participants within two days of each Challenge session, I was able to ask questions about their experience while those experiences were still fresh in their minds. This was the same timeframe used in the pilot study (which included one of this study's participants, Jane) and was generally agreed to be an acceptable amount of time after interviews, as opposed to keeping them after school to interview the day of Challenge or waiting until after a weekend had passed. These interviews, combined with the pre- and post-Challenge interviews held on the day with the instructors and my own observations, ensured that this form of lesson-centred data was as complete and accurate as possible.

2.6.2. Learner-focussed sources of data

Learner-centred data was collected just prior to, during, and after the unit itself and were derived primarily from student interviews, though the lesson observations also in many cases qualified as learner-focussed as well. The interviews were, where possible, held twice a week- one interview before the week's Challenge day, and one interview after. This schedule (Tables 3.2 and 5.1) allowed myself and the student to consider ahead of time the lesson for each week and establish a baseline, while the meeting after allowed me to ask targeted questions based on the observations (or to catch up on events I missed due to the observation schedule), and for the student to reflect on what they had experienced. This not only allowed me to verify events

observed during the project itself, but allowed students time to consider anything they had learned before discussing it. This was valuable, as there is some variability in terms of the point at which learning takes place[16], as well as when students become aware it has taken place (Domin 2007)

These interviews were conducted one-on-one and primarily in a manner similar to that utilised by Adbo and Taber (2014) for eliciting evidence of student conceptualisation, described by White and Gunstone (1992) as an interview about instance (IAI). In this study, a variety of stimuli were used, including drawn images, incidents from the observations, and physical objects, including a series of images (Appendix A.11) used in a manner similar to the card deck suggested by Gilbert, Watts, and Osborne (1985) for using IAI as a research method. This was done because different stimuli may trigger different types of responses from the students (White & Gunstone, 1992). These interviews were exploratory in a sense, attempting to establish what concepts the student possessed that they associate with the given stimuli. While some prompts were offered, the interviews were primarily semi-structured once they had been offered, and follow-up questions or prompts often changed as a result of the preceding interactions. Data collected on one week also influenced the structure of the following interview sessions; a prime example of this was with Hamish, where his inconsistent word choice led to a session spent trying to make more explicit his understanding of certain vocabulary. The concept map (Figure 3.3) derived from this session then formed the basis of future interviews.

The variety in the structure of the interview periods was due to two primary factors, the first of which is that each student was following a very different trajectory within their projects, which involved different learning. For the CS project, the initial interviews were structured the same for both Hannah and Jane, but as their roles diverged, so too did their interviews. In the case of Jane in particular, this led to far greater enthusiasm within the interviews, as they were based around her area of interest. Certain prompts were still used for both participants as the challenge went on, however, as there was still come crossover in their experiences and developing skills and understandings. Hamish's interviews in the WMP differed not only from Hannah and Jane's but from one another. This was because his project itself had greater variety

[16] This relates somewhat to the assertions in the introduction that changes in behaviour need not be immediate to constitute learning. However, the point here is that the potential for that change may *also* not occur immediately upon exposure to the stimulus

in terms of learning targets, and so the interviews were adjusted to best explore his learning in any given session.

Interviews were all audio recorded, and all physical artefacts such as student drawings or annotations generated were collected for analysis. In later interviews, interview foci included notes from previous sessions or in one case a concept map (Figure 3.3), which the student was encouraged to comment on or amend, to elicit new data and correct any inaccurate assumptions I had made which could pose a threat to internal validity (Yin, 2014). It also demonstrated to the student that their words have value, and can help to build rapport which can help the students to feel more comfortable.

Students also controlled the duration of each interview, where the first portion of each interview was structured according to pre-determined prompts and foci and the second portion was based on their responses and their level of enthusiasm each day. Because each student determined what was most comfortable for them in this section, the average interview duration varied from student to student, with Hamish's interviews frequently running from 30-45 minutes in duration, Hannah's approximately 20 minutes, and Jane's typically less than 20 minutes. The range can be seen as a result of the personality of each participant, with Hamish enjoying the free flow of information and a number of tangents which often extended the interview considerably, where Jane was much more concise in her speech and often chose not to pursue any discussion beyond the structured prompts. While it would have been possible to push Jane (and Hannah) for more information or Hamish for less, this student-driven duration of the interviews meant each student had a greater say in the telling of their narrative, and this was the deciding factor for me in terms of the structure of the majority of their interviews.

The final interview for each participant contained elements of both interview about instance (IAI) and interview about concepts (IAC), while also containing significant portions of time dedicated to more loosely structured questions. Students were asked to react or reply to certain events from all stages of their projects, particularly those that arose from their final presentation days. Unlike in previous interviews, the concept being looked at was clearly defined for the student ("argue for or against the idea that a computer is like a well-behaved dog", in terms of the relationship between the programmer and the computer) and subsequent questions moved from the general to the specific, based on student responses. While a list of follow-up questions was prepared, the list was not meant to be prescriptive or exhaustive, and as

in previous weeks, the student responses set the tone for these. The order and scope of the questions often had to be modified within the interview to suit responses and to keep the student as ease and willing to continue. Students were also asked more explicit questions regarding their beliefs about the efficacy of certain lesson elements, and were provided minor corrections to some of their previous responses and asked for their opinions. This was the only time this was done, in an effort to prevent teaching by interviewing (White & Gunstone, 1992).

The data collected from these interviews, both the verbal communication and the physical artefacts, had to be compiled and presented in a manner that allowed for a proper analysis to be conducted. This included consideration of the transcription of each interview. While no transcription can attempt to perfectly capture the body language of the interviewee or the subtleties of tone, a number of steps were taken to ensure as faithful transcription as possible. Five to ten minutes was taken after each interview to make notes about the participant's tone or attitudes during the interview, including any comments made before or after the recorder was turned on. Then, every effort was made to transcribe as soon as possible after the interview, ideally within a day or two depending on the interview schedule (Gillham, 2005). Finally, all transcription work was done myself, as Gillham (2005) also states that analysis begins in the transcription phase due to how deeply the material must be considered. Each interview was first listened to in its entirety, then transcribed line by line. The audio was then played back while reading the transcript to check for any errors. A final check of the transcriptions against the audio was done just prior to the formal start of the analysis process as well.

2.7. Data analysis

The purpose of the data collected in each case is to help produce both an overview and a highly detailed description of the developing skills and knowledge of each student, through the process of analysis and interpretation. The data was analysed in multiple stages, starting with data shared by all cases (school-specific data, observation data) before progressing to individual data (interviews and artefacts) and then finally to a comparison across the cases. A narrative of each method of analysis is given here, and summarised in the tables in Appendix C.1.

The lesson plans collected as lesson-focussed data were compiled and analysed in two ways. First, the project overviews were annotated and coded according to objectives. The primary interest was whether the tasks expected of the students were leading to a change in foundational or conceptual knowledge, procedural skills and knowledge, or transferrable skills and knowledge. Student motivation was also considered. These were coded independently by me, although in several places, the instructor added their opinions on the nature of the day's instructional aims. These codes were derived as a compromise between Anderson et al. (2001)'s revision of Bloom's taxonomy, and Fink's (2013) taxonomy. A table of codes can be found in Appendix C.2. It should be noted that the coding for the lessons was more general than the coding for the interviews; the code groups rather than the individual codes were used.

Before codes could be determined, it was necessary to develop a strong familiarity with the data. As mentioned in discussion of the data collection methods above, the transcription itself served as an initial round of analysis, from which codes could be derived based on themes derived from the text (emergent coding). Under the general headers relating to content knowledge, procedural knowledge, transferrable skills, and motivation, codes relating to examples of learning under these categories were determined. A fifth category, conceptions, was used for the Water Management Project, but not for the Computer Science one. This is because the aims for the CS project (as laid out in the project brief) prioritised the other forms of knowledge, and familiarity with both CS students' cases suggested their learning had been focussed on procedural knowledge and transferrable skills, rather than content-based concepts. This is not to say that no conceptual learning took place, but rather to suggest that learning in other knowledge dimensions (Anderson et al., 2001) was the focus of this project.

The same coding scheme that was used for the project briefs was also used to code all lessons and artefacts produced by the students when looking at the learner-focussed data. This was done because the second research question deals with the link between the lesson elements and the student learning, but also because it may reasonably be expected that teaching objectives are written with the intent of leading to learning of a similar nature. What I discovered quickly was that there were many instances in which the same code could be applied; this was not unexpected. Because the purpose of the codes was to act primarily in the manner of an index (Bernard, Wutich, & Ryan, 2017), and because no two examples of, for example, communication, were going to be the same, this was not a major concern. The primary purpose

of the coding was to group together portions of the data that shared similar properties for the second phase of analysis, and they were used successfully in this manner.

The second phase of learner-focussed analysis involved grouping selected quotes by code in separate Word documents, in order to allow for the analysis of specific content categories. The determination of which code groups to select was the most subjective decision of the entire analysis process; while it was based primarily on relative frequency of code use, it was also based on the nature of each student's narrative (Lieblich, Tuval-Mashiach, & Zilber, 1998). Jane for example had stated that her role was that of report writer and organiser, rather than programmer. The most meaningful learning for her was more likely in the areas of consumer focus, communication, and planning than in programming logic and knowledge of syntax, though these areas were not entirely abandoned. These codes allowed for the formation of categories within the data, which could then be separated out and considered independently before being considered in conjunction with one another. In the cases of Hannah and Jane, their data could also be used as a means of member checking, as they were part of the same project group and could offer perspectives on the same events, and so their narratives relating to particular incidents were often considered together.

The result of this second phase of analysis was the decision to document Hamish's conceptual changes as his primary form of learning, while for Jane the primary focus was on transferrable skills. Hannah's learning was harder to classify, for the conceptual understanding she developed during the project manifested primarily in procedural knowledge due to the nature of her tasks. This means that, while the focus of her narrative is presented primarily as procedural knowledge, it is inextricably linked with her increasing conceptual understanding as well. For Hamish and Jane as well, learning took place across all of these dimensions, but in order to allow my narratives to remain faithful to theirs, a decision was made to allow the nature of their stories to determine what formed the focus of their learning in their projects. These foci were determined through the establishment of multiple documents for each learner, based on the categories established above. The analysis of these involved comparison to the baseline gathered in the initial interview, and from that baseline I looked for changes in complexity of conceptual knowledge/applied task, or integration into other areas. It was evident from this second round of analysis that the focus and nature of learning for each participant was quite different, and so one or two of the potential learning categories (examples include consumer focus, programming

logic, conception of biodiversity) for each participant was selected for further analysis. This involved in some instances a subjective determination of learning, based on my familiarity with the participants. This is in line with the interpretivist framework adopted for the methodology.

The above phases resulted in sufficient answers to the first research question, relating to how students learn over the course of a PBL project. In the final phase of the data analysis, the lesson-focussed and learner-focussed data were considered together to evaluate what impacts the lessons themselves had on learning, as a means to answer research question two for each case. This is not to suggest that either was ever viewed in true isolation; the preliminary analysis (transcription phase) informed the coding and analysis of the lesson-focussed data, which in turn then influenced to a degree the coding and analysis of the interviews and artefacts. This was not only the most efficient method I could contrive for the analysis; it was also in line with the interpretivist framework I had adopted for this study.

2.8. Ethical considerations

When working with vulnerable populations such as young people, ethical considerations must be at the forefront of every decision-making process. While all data collection and analysis was done in line with BERA (2018) ethical guidelines, certain suggested considerations were more relevant to this study than others. It is the intent of a case study to describe in-depth a particular instance, and this involved creating as minimal impact on the participants' behaviour as is possible, as well as taking all possible measures to treat all participants with dignity and respect, as per BERA (2018). This began with ensuring that all participants are aware of the aims and design of the research, so that voluntary informed consent is even a possibility.

In terms of this consent, it had to be clear at all times what the participant was consenting to, and that said consent could be withdrawn at any time with no negative consequence to the participant. While consent was obtained from both the underage participant and their parent or legal guardian, the participants were reminded that they had the right to withdraw their own consent at any time, even if their parents had previously given consent. In this way, each student involved in the research felt comfortable with their participation or was free to withdraw should

this no longer be the case. Students were reminded of this at regular intervals, and except for one moment where a student dropped something and made reference to me 'just editing that part out' in jest, no dialogue was requested to be withheld.

While all efforts were made to minimise the time impact of the study, students were also made aware that they may withdraw permanently or temporarily if participation is having a negative impact on their time management. In several instances with Hamish in particular, sessions were moved to accommodate his workload. Students were not compensated for their time to avoid any form of coercion, but students did feel in some cases as if the interviews benefitted them by encouraging them to make their ideas explicit. This was considered prior to the start of the study and determined to be an acceptable compromise which created a benefit for the students, but not one that could be considered coercive.

In order to protect the wellbeing of the participants, privacy and the storage and use of personal data had to also be carefully considered. Each student was kept anonymous through the use of a pseudonym[17], and any unique identifiers in the transcripts were redacted unless explicit permission was given. The participants were also invited to identify the most comfortable interviewing location for themselves, to allow for as much privacy as they desired. All of the students were quite comfortable with being identified internally and so did not concern themselves greatly with interview locations beyond consideration for noise levels, and they all agreed with the procedures undertaken to protect their data. Student participants were then also being given the opportunity to decide what data is returned to them, and in what form. They were told they may ask for the thesis chapters relating to themselves, or may ask for a simplified format as well. At no time however will I agree to write or publish any information that is false or misleading, even to protect the student. In cases where this would prove necessary, the relevant interviews or artefacts would have been removed rather than altered. Fortunately, no such instances arose, and all of the data remained intact and in its original form. In such a way was it possible to also protect the integrity of the work as well as the welfare of the student.

[17] This applies to all students mentioned in any of the later chapters. The participants each selected their own pseudonyms, and I assigned pseudonyms to each other student they mentioned in their interviews

2.9. Limitations

Naturally, any study conducted will have limitations of one variety or another. In selecting a methodology and associated methods, a cost-benefit analysis is done to determine what the most important and relevant outcomes might be. When choosing the case study, I sacrificed breadth for depth, particularly in terms of number of participants. While some case studies in this area focus on large numbers of students (Fang et al., 2016) and are able to produce more generalisable findings, they lose the richness of the narrative that comes from close contact with the subjects. Because in this instance each case was defined as a single student, I felt the priority was on in-depth interviews and observations, rather than large scale assessment. While this may well lead to a rich narrative, it also means that the results do not readily lend themselves to generalisation. The use of multiple cases does make certain findings relatable to a wider variety of other individuals, but the purpose of a case study is not necessarily to produce findings that can be applied on a global scale.

Limitations related to data collection also occurred. The student cannot, for both ethical and practical reasons, be observed and recorded throughout an entire day. The fact that two projects ran simultaneously meant that observations in one project were at the cost of observations in another. This was addressed in section 2.6.1, but while every attempt to mitigate this was made, there is still a likelihood that a valuable interaction was missed at some point. This was partially addressed by asking each participant to recap their Challenge days at the next interview session. I also then asked about the observations I did make, as a form of member checking, and as a way of verifying the timeline. Additionally, because students were interviewed only within the school setting, there is no record of how they may have interacted with the material outside the school day. The frequency of the interviews was set to mitigate this as much as possible.

Concerning the interview schedule, there were a few unavoidable adjustments. In the first instance, all interviews between the 3rd and the 10th of May 2018 were cancelled due to a major family event on my part, which required me to fly back to America. No Challenge sessions were missed as a result but the post-Challenge interviews for the 2nd of May, and the pre-Challenge sessions for the 9th of May, could not be held. A longer session for each participant was scheduled for after the 9th of May as a means of catching up on anything that was

missed. Student schedules also meant less predictable changes to the interview schedules as well. Even in instances where interviews were held regularly, such a system also presents limitations in the form of the possibility that sequential interviewing may have resulted in changes to the way the participants viewed their projects, as one participant noted "the only real reason I've been thinking about it is because of your questions about it" (Hs18.06.11 lns 157-158). Repeated discussion and consideration of the concepts being presented may lead to increasingly complex description, which in turn could suggest learning in the form of conceptual change (Reif, 1985). Careful analysis of the data is therefore necessary to separate out to the extent possible changes due to the interview protocol.

In the end, a well-designed investigation will allow for such limitations, and I feel that such is the case here. While not all limitations can be accounted for, every effort was made to mitigate the impact of the limitations inherent in the design of this particular study, and of the case study method in particular. While the case study method means there cannot be the same sort of generalisation as might be possible from a large-scale quantitative study, the richness of detail here I feel provides valuable insight into the student learning process from three quite different perspectives, and thus this study represents a new and valuable addition to the body of knowledge relating to student learning and experiences in this educational setting.

CHAPTER 3- Hamish and the water management project

The purpose of the following two chapters is to explore the experience of a single student, Hamish, as he undertakes a Challenge project at Cambridge Academy for Science and Technology (CAST) in the early spring of 2018. This chapter will introduce the project, and explain Hamish's background sufficient to provide context for his experience with the project. With these details established, I will then provide a narrative of Hamish's engagement with the project. The next chapter will incorporate some of this as it explores Hamish' changing conceptions of biodiversity, before then attempting to connect both his engagement and his conceptual change to the teaching methods used throughout the Challenge Project. As a note here, Hamish tended to be almost lazy in his word choice at times, which in some cases will be addressed in context below. Other instances had little impact on meaning but are worth addressing, specifically his term for the waterway they were studying. Hamish uses the terms 'Hobson's Brook', Hobson's Creek', and 'Hobson's Conduit' interchangeably, with no apparent conceptual justification for his choice in any particular instance.

3.1. The water management Challenge project

The Water Management Project (WMP) was, unlike many of the projects run at CAST, facilitated primarily by school staff, and supported by a variety of local experts and employers. This for the most part meant bringing in speakers to instruct on various topics (See Appendix A.1), though several field trips were taken under the supervision of both CAST teaching staff and members of relevant local authorities. This varied structure fed directly into the outcomes and objectives of the project, notably 'produce a management plan for a local river' and 'Be able to weigh up complex and competing needs to reach a workable outcome'. Speakers included employees of Anglian Water, researchers from a variety of departments at the University of Cambridge, and volunteers from the Hobson's Conduit Trust, an organisation that concerns itself with the preservation and maintenance of the local waterway. While there were activities spread throughout, notably multiple trips through Nine Wells[18] and along the conduit, the majority of

[18] Nine Wells site consists of several spring heads near the Cambridge biomedical campus, and is the source for Hobson's Conduit, a local Cambridge waterway running from the Nine Wells site to the centre of town. Both of these can be seen on the creek walk map in Hamish's report in B.3

direct instruction was concentrated on the first day. While students remained alert and interactive through the lectures and panel discussions, Hamish at least was of the opinion that there was a bit of an overload, and he did not retain as much information as he could have had the lectures been distributed more evenly across the available time. (18.06.11, lns 430-438[19])

> Hs[20]: I think it's having these lectures um so I can get the basic information but then using that information so I feel like there was too long a period in which we learned the information and didn't apply it um and so like I said we got all of these lectures we got all of this information perfect we then moved on and I can't remember what the first task we did after that but it only applied some of that and then it kept going it only applied to some of that only applied to some of that etc. etc. and I feel like by the time we got to you know seven well seven weeks that's a complete lie because then the project would have been over but we got to like a few weeks down the line and we were dealing with activities in which we needed to know this information but it had been so long we'd forgotten it

This being said, the majority of issues discussed during the first week did come up again during the interactive lessons later on, and in some instances seen below, Hamish was able to recall some details presented in that first lesson.

Thematically, the course focussed primarily on the biotic and abiotic factors that were influencing the health of the Nine Wells ecosystem, and the implications this had for the management of the local water supply. These were introduced together in the introductory lectures in the first week, and then considered individually as the course progressed. The sequence of some activities (Appendix A.1) was adapted to accommodate collaborator schedules in some places and other activities, notably the visit to the Eddington site, were cancelled due to external factors. Students were however given multiple opportunities to view the ecosystem directly, and were able to collect and test samples from the site with consideration to both biotic and abiotic factors. In particular, the 21st and 28th of March focussed on weather patterns and

[19] Referencing of direct quotes from interviews will be noted with the date of the interview and the lines from the transcript

[20] Hs is used to indicate quotes by Hamish. A two letter abbreviation is used to avoid confusion with another participant, Hannah, who is designated Hh.

water quality, and the 18th of April included kick sampling to allow the collection and study of aquatic invertebrates. Students were then given the opportunity to tour a water treatment plant on the 2nd of May, where they were able to observe several of the chemical tests they had performed in class in a large-scale facility.

The project outline also included transferrable skills to be developed, referred to in the document as Teaching Objectives. As might reasonably be expected in a group project, these included planning ahead, sharing data, and communication within the group. Interestingly, these objectives specifically include a point about carrying on when a group member is absent, perhaps suggesting this is a common occurrence. Indeed, pre-observation conversations did establish that pupil attendance was a continued focus for the school, based on recommendations from a recent inspection (OFSTED, 2017). Students were also asked to 'understand how modern data collection techniques can aid in data collection in the field', rather than being expected to use the techniques directly. The distinction is a significant one; while many data collection techniques were taught to the students, others were impractical due to constraints in time and/or resources, so in these cases, a discussion of collection techniques could be presented alongside the collected data. The final teaching objectives, 'Be able to present results to a mixed audience' and 'Develop teaching skills' directly relate to the final two weeks of the project, where students were expected to develop and deliver interactive lessons to primary students visiting CAST for the day, which is discussed in greater detail below.

Returning to the expected Outcomes of the WMP, students were tasked with three: a management plan for the river, a catchment conceptualisation map, and an event for local primary students. In the early weeks of the project, students were given significantly more guidance in relation to the first two, with the catchment map the focus of 14th March (Week 2), and the management plan spread across Weeks 3-7 (Table 3.2). Week 8 was given to the planning of the primary activities, and Week 9 saw the primary students come in for the day and the CAST students delivering the lessons they had planned out the week prior. Because the primary day ended up having a slightly different focus than the management plan (Hamish will later refer to this as a report), the three outcomes can all be said to be connected to different objectives, with most directly related to the first outcome (Table 3.1). This determination was made after the completion of the WMP, as a result of observation and review of student experiences; for some groups, there was significantly more overlap between the Primary Day and

their management plan, based on the nature of their Primary Day activity. It should be noted that while I matched each objective to one or more of the outcomes provided, the classification of each as either 'teaching' or 'learning' came from the course outline directly. This will be explored further in the impact of instruction section of the next chapter.

Table 3.1. WMP objectives categorised by observed outcome, adapted from (CAST, 2018).

Outcome	**Produce a management plan for a local river**	**Make a catchment conceptualisation map**	**Deliver an event for primary school students based upon water management**
Learning Objectives	Learn a range of biotic and abiotic sampling and analysis techniques		
	Understand how biological, chemical, and physical measurements can influence the health of a river		
	Be able to break down and understand a complex ecosystem	Be able to break down and understand a complex ecosystem	Be able to break down and understand a complex ecosystem
	Understand how competing pressures impact upon a river		
	Understand how human needs can put competing needs on a river		
	Be able to weigh up complex and competing needs to reach a workable outcome		
Teaching Objectives	Develop skills in managing a group when not all members are present and able to work directly together, including planning ahead, sharing data, presenting data to the rest of the group so all are aware of how the project is developing		
	Understand how modern data collection techniques can aid data collection in the field	Understand how modern data collection techniques can aid data collection in the field	
	Be aware of the safety issues associated with field work	Be aware of the safety issues associated with field work	
	Be able to present results to a mixed audience		Be able to present results to a mixed audience
			Develop teaching skills

Students were provided with various supports as they went through the project; each day could in a way be viewed as discrete, with the majority of sessions consisting of a similar format that included a practical component in the morning. A prime example was the 18th April, focussed on biotic factors; students spent the morning taking kick samples from various points along Hobson's Conduit, returned to the classroom to do an invertebrate count, and compile their data (Appendix B.1). At the end of the day, they engaged in a discussion about the meaning of their results, and were given time to add their findings to their growing reports. It was during the later portion of the day, the report writing, that students had the opportunity to differentiate their roles; all students were expected to participate in the practical sessions. For the majority of these afternoon sessions, links to various resources were provided via cloud-based document sharing,

though some independent research, via internet search engines, was necessary and encouraged for certain topics. The effectiveness of each of these lessons will be considered in parallel with Hamish's narrative of the course, with additional detail where applicable.

3.2. Hamish's background

The Water Management Project was quite a popular choice when students signed up, to the extent that some were moved to their second choice projects. Hamish was an odd exception to this; he was absent the day of the project sign-ups, and would have preferred the Computer Science project had he been given the choice, despite his interest in Biology. Hamish was relatively new to CAST, joining for sixth form from September 2017. He had come from a private study centre, having first attempted and failed his GCSE's at his original secondary school. Hamish self-identified as suffering from dyslexia and dyspraxia, which had resulted in him being denied a place in higher tier[21] for any of his courses at his previous school. This in turn, he feels, led to his 'giving up' and then getting 6 D's, an E, and a G[22] the first time around. His self-efficacy seemed quite tied to his performance; when he went to retake, "when I went to this private school place they put me on higher tier for everything I tried and I got good marks" (18.03.02 lns 18-19). While there is evidence that motivation and self-efficacy can have a significant impact on students resitting their GCSE's (Anderson & Peart, 2016) that this improvement is due entirely to the self-confidence that resulted from his placement in higher tiers is doubtful. Increased familiarity with the material is likely to have played a part, as will have his familiarity with the testing process. Regardless, the success he was able to achieve (1 A, 3 B's, 3C's) meant he had more choices for sixth form.

Because Hamish already knew he was interested in pursuing a paramedic qualification after his sixth form, he chose to enrol in the Applied Sciences BTEC with Core Maths as an additional subject. He was quite enthusiastic about his coursework, believing it gave him advantages his peers might not have because of the breadth of subject matter he was being

[21] In the UK, students sitting their GCSE exams may be entered at either a 'foundation' or 'higher' tier, reflecting relative difficulty of examinations. These tiers are determined in advance, so students are aware of which tier they are in.

[22] GCSE marks were at the time of Hamish's assessment awarded on an A*-G scale, with scores below G resulting in no qualification being awarded

exposed to; diverse knowledge over specialised expertise was a relatively common theme throughout our time together. Hamish also believed that the BTEC qualification allows him flexibility in terms of the pathway by which he can pursue his qualification; he could pursue either an apprenticeship or a degree in paramedic science. As the project progressed, it seemed as if he was leaning more towards the apprenticeship option, but from the start he was clear that whichever pathway he chose, it could easily be extended to then later study medicine and become a doctor, pursue an advanced paramedic qualification, or another undetermined path. Hamish definitely believed that having options and flexibility in his courses was important to him, as it meant he would have more options and flexibility in his future.

When asked about his specific background that could be relevant to the WMP, Hamish was a bit more cautious, feeling his primary background was more within the realm of human biology. While an A Level in Environmental Science was an option offered by CAST, he chose not to take it, and had done very little independent work relating to Ecology in the past because "if I don't find a subject interesting, I don't really get motivated to learn about it" (18.03.02 lns 142-143). When pressed, Hamish did admit he was open to the idea of becoming more engaged and involved in Ecology, but the project as it had been presented to him was not one that immediately grabbed his attention. This would become a major theme as the project progressed; not only was this evident from his behaviour, Hamish remained very good at identifying this characteristic in himself as he went along with the project.

Hamish held equally decisive views about his learning style as well; when he did find a topic to be interesting, he preferred to ask increasingly complex 'but why' type questions until his curiosity was satisfied. More than once, he joked that while most teachers say they want students like this, he felt he was actually an annoyance to them (18.03.02 lns 47-52):

> Hs: Oh yeah no I mean obviously all schools have this whole motivation of 'oh we love it when you ask why' and then I found out that when you ask why 15 times they tend to not like it um but no these Challenge Projects are great in the respect of discovering more and doing a little bit more in-depth research than you would typically do in lessons because you get people coming in the subject field and they're always happy to talk about their work um so it's really good to go in-depth with them about it yeah

Because Hamish believed that experts were more amenable to an ever-increasingly complex series of 'but why's, he was anticipating being able to go more in-depth than he would have the chance to go during his courses. This was very important for him, because when he described his preferred learning style, this was one thing he felt he did not get enough of during typical lessons (18.03.09 lns 65-67…71-72):

> Hs:…my uh personal preference is I love a teacher who's always happy to sort of be there and answer questions, even if it's not necessarily about what we're doing… cause for me gaining a better understanding is always about asking 'why okay why does it happen oh it happens because of this I now understand why it happens'

With this in mind, Hamish was willing to participate in this new project, despite being outside his general area of interest, because (18.03.09 lns 18-22):

> Hs:…some topics where I've um looked at I've gone I'm not amazingly interested by this like uh lenses in Physics like convex and stuff um I've looked at it and gone I'm don't really find this stuff interesting but then once I've learned a little bit more about it, I've found out more about what it's about I've gone yeah okay I find this quite interesting.

The opportunity to work with experts in the field, who would give Hamish the chance to ask questions, learn more about the topic, and perhaps discover a new interest was enough for him to enter this project willingly if not entirely enthusiastically.

3.3. Challenges associated with the project

Hamish's case presented unique challenges in that he was absent for all or part of the Challenge day on multiple occasions due to illness or scheduling conflicts (Table 2). This meant he had to rely not only on the experiences he had in Challenge but also on recaps provided to him by his group members. Due to a general disengagement[23] with this project, these were

[23] In this case, this refers to Hamish's entire group, who all expressed disinterest in the project at one point or another

infrequent and quite brief. The lack of engagement with the material was likely the reason he chose not to seek a more detailed recap of missed sessions, though he was willing enough to discuss and in some instances even make up some of the missed work during his interviews. A session in which he was asked to review several photos of specimens from the kick sampling day is a prime example of this; he and I went through in an abbreviated form the process his peers used to identify aquatic invertebrates and then Hamish was asked to interpret what their presence meant in terms of water quality. As with other interviews, every attempt to do this without teaching or leading was made, but the bigger concern is that Hamish missed out on the chance to learn through his peers, rather than working by himself through a sample of their data. Whether this had an impact on his understanding I cannot be sure, although he explicitly stated he was at least willing if not particularly interested in such catch-up sessions.

Table 3.2. Timeline of Hamish's interviews and Challenge sessions. Challenges where Hamish missed all or part of a session are highlighted

Week #	**0**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**00**
Week of	**02.26**	**03.05**	**03.12**	**03.19**	**03.26**	**04.16**	**04.23**	**04.30**	**05.07**	**05.14**	**05.21**	**06.11**
Interview 1			03.12	03.19	03.26	04.16	04.23			05.14		
Challenge		03.07	03.14	03.21	03.28	04.18	04.25	05.02	05.09	05.16	05.23	
Interview 2	03.02	03.09	03.16	03.23			04.27		05.11	05.18		06.11

There were also missed appointments and long gaps in our interviews due to his work placement, among others. What this meant in the end is that often, multiple sessions' objectives were sometimes combined into a single interview, allowing Hamish to perhaps form connections during the interview itself. This was not wholly unexpected; Champagne, Gunstone, and Klopfer (1985) describe a situation in which as the student becomes explicitly aware of his or her conceptions, dissatisfaction with current theories may occur, which could lead to a change. While perhaps not explicitly aware that this was happening, Hamish did feel that the interviews gave him a chance to sort out his thinking, for which he was grateful.

Because this project was one of two projects being observed within the same time period, it was impossible to be in either project full-time, and thus some exchanges or important moments may have been missed. As a general rule, the Computer Science (CS) project also being observed required the students to be more independent than did the Water Management project. This meant daily tasks in the CS project tended to vary less than for the WMP so when

there was a choice to be made, more time was spent observing the WMP. However, Hamish's relatively frequent absences or early dismissals meant that on those days, a brief meeting with the instructor regarding the aims of the session beforehand, and a recap after, were sufficient to generate prompts for the interviews. I realised early on that when Hamish and I were meeting following a session he missed all or part of, there was a potential risk that I would be leading. As stated in the methodology, especial care was taken to ensure none of the questions presented information Hamish had missed previously, instead drawing out what he had been told by his peers upon his return or, as above, presenting him with information that had already been given to his classmates. While overall this may have led to less information, what data was collected is certainly quite detailed and informative, and allows a clear picture of Hamish's learning to form.

3.4. Hamish's conception of biodiversity

In a project whose objectives and aims were explicitly concerned with the management of a local river (Appendix A.1), Hamish recognised the importance of water management but felt there was a different primary focus (18.05.14 lns 387-397):

> R[24]: Is particularly what would you say would be the overall theme of this unit if you had to pick one word from these papers what would that one word be?
>
> Hs: So specifically one that's on this paper?
>
> R: Mhmm
>
> Hs: Oh okay um well I would say biodiversity
>
> R: Okay
>
> Hs: I mean very much so I mean yes I I've put all these other sort of big sort of title headings consumption, development, competition yeah they are very prevalent in what we're talking about but I think if I had to pick one main one for what we're doing we've all been looking this whole topic about how these different things cause a change in the biodiversity and so yeah I I'd say that's quite clearly an overall header for me

[24] Researcher

When presented with a list (Appendix A.2) of terms that had been repeated frequently either in Challenge or in interviews, Hamish selected 'biodiversity' a bit hesitantly at first, but was very quickly able to justify this to himself and to me. He had by this point been presented with the formal objectives during a Challenge session, but still he felt that the real aim was to understand how the management of the water supply, monitoring, etc. would impact the biodiversity of the Nine Wells ecosystem. By Hamish's own admission, he had little background knowledge in ecology and only a vague understanding of biodiversity prior to the project, so an exploration of the changes to his conception of biodiversity should provide an illustration of learning, as it has been previously defined.

3.4.1. Hamish's early conceptions of biodiversity

Hamish's first exposure to biodiversity in this project came in the introductory lectures, where the *loss* of biodiversity in the face of environmental changes, as well as an overview of the current biodiversity of the Nine Wells site was presented. Hamish was in an interactive panel discussion quite passionate about finding a balance between human needs (health-related, financial, or otherwise) and the ecosystem, contributing the majority of his group's opinions in the discussion and offering potential compromises such as a reasonable water-use cap for homeowners. He did not focus on the environmental impacts so much as the human needs and how they might best be met with minimal impact. When we met shortly after the first of the project days, these concerns over balance formed the majority of our discussions, and it was only when I asked Hamish to draw out a prediction of what he would see at the Nine Wells site did the native inhabitants of the site come up at all (18.03.09 lns 303-309):

> Hs: Vandalism at some points, litter dropped at some points um this this is what I'm assuming oh he he said there were um oh tons of wildlife it was something like over 50 species of bird and frogs and toads being the main amphibians so presumably seeing a decent amount of wildlife yeah actually especially considering this is the only real environmental piece of land for a while in this urban environment yeah I'm expecting there to be a decent amount of wildlife there although I won't I won't bless you with my amazing drawing of toads but some form of that some form of that

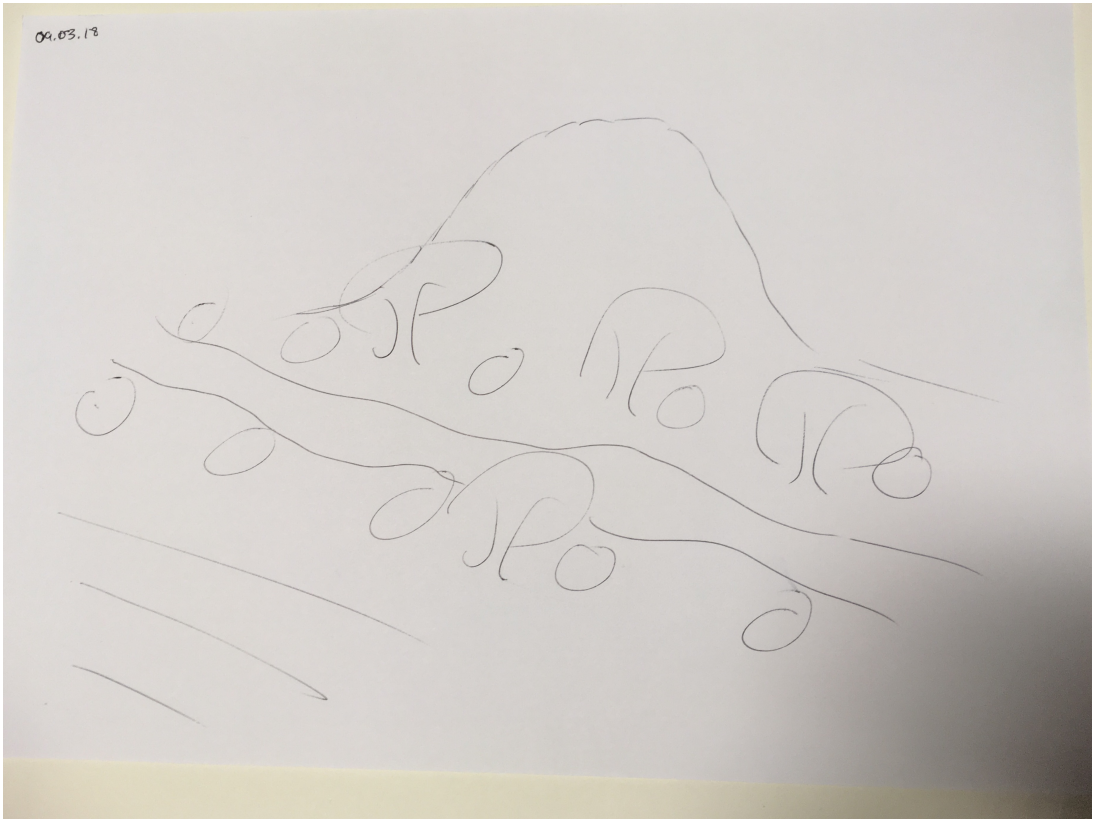

Figure 3.1. Hamish's initial predictions of the appearance of the Nine Wells site, 18.03.09

At this point, Hamish had established that there was reported to be a large variety of bird species present, but gives the matter only a glancing thought. It is only when we were speaking the following Monday (again prior to the Nine Wells visit) that the relationship between biodiversity and ecological health was discussed (18.03.12):

> Hs: …in terms of how the organism naturally develop- how the ecosystem naturally develops then no humans wouldn't be the main influencer, it would solely depend on the type of animals, the type of organisms present whether they were larger numbers or fewer numbers of a certain one…

Biodiversity at these early stages was perhaps seen merely as one of the factors influencing the health of a given environment, much in the same way that human inhabitants and their associated

impacts be seen as being equally if not more influential in determining overall health (Hamish actually continues in this vein after the quote above).

After Hamish was given the chance to explore the site (the class walked through the Nine Wells recreational area and along Hobson's Brook to the conduit head in town), Hamish paid a bit more attention to biodiversity, particularly the lack of it. In particular, his early concerns relate to the variety of fish that might be found in the stream because the environment is not one that encourages them to flourish. It makes sense that this would be the case; much of what Hamish had focussed on to this point was how to increase human appreciation for the site to inspire conservation efforts. To Hamish, biodiversity remained an indicator of ecological health, but because a healthy variety of fish means sport for anglers, it could also be a means to an end (18.03.16 lns 220-227):

> Hs: …so I'm sure that obviously if Nine Wells became if we started improving it and it became a lot better and we got a larger population of all of these all of these um fish and other such creatures you would see an increase in popularity for these people and at that point I reckon you might to see a …slightly increased appreciation um for the area cause you'd certainly get all of these people fly fishing they'll come in and if it's managed properly then that's certainly a good thing for the environment it brings in um I mean yeah you kind of are disrupting the wildlife out of their natural habit but you're also allowing people appreciation of the space

Because Hamish also believed that increasing appreciation for the space would inspire the public to take action to conserve the space, biodiversity could then play an indirect role in conservation. This is by no means a unique idea; rebuilding or maintaining fisheries is often used as a public conservation objective, and it can be argued that the primary benefit of zoological gardens is to increase public support for conservation efforts (Hutchins, Smith, & Allard, 2003). Because it does tie-in so well to Hamish's priority of educating and mobilising the public, it is unsurprising that a well-stocked fishery was among his primary concerns.

3.4.2 Changes to Hamish's conception of biodiversity

At approximately the midpoint of the practical sessions for the WMP, the students were presented with a pamphlet by Anglian Water regarding their biodiversity strategy, a '19-page document' that Hamish was immediately put off and mildly insulted by (more on this in Chapter 3.5). Because Hamish had merely skimmed through the material, he "couldn't find any information specifically as to why Anglian Water was um uh taking into account the biodiversity of the area and changing their plans accordingly". Despite this, Hamish was in a way able to find meaning in biodiversity, in perhaps a way he hadn't earlier (18.03.23 lns 159-175):

> R: What well why would anyone want to make efforts to maintain biodiversity?
>
> Hs: Well it's our future really isn't it? Um well maybe not necessarily our future but the future umm and in very basic terms if we screw up the future we're pretty much screwing up ourselves umm I believe Stephen Hawking said that one…there will be many reasons but my main one that I sort of envisualise is the fact that by decreasing all of this biodiversity we're only making conditions worse for ourselves and so that's quite a selfish way of looking at it in terms of the whole human development and everything … the less selfish kind view were it is also destroying the world around us and it's destroying all of these amazing species that are essentially going down the drain cause we can't afford to maintain what they're giving to us or maintain their habitats that we use for our own personal gain so yeah the main one is it will uh make it harder for us in the future but also it will uh it will make it harder for a lot of other species living on this planet

Beyond just fish in the stream then, Hamish sees a healthy level of biodiversity as critical for our survival as a species; while he was vague as to the exact mechanisms by which it might happen, he warned of dramatic social and economic consequences should biodiversity not be maintained.

While his view of biodiversity certainly at this point still holds an element of anthropocentrism, he is starting to see consequences beyond the Nine Wells ecosystem. He

tempers this by acknowledging that beyond the selfish desires of humanity, there is an inherent obligation to maintain habitats to protect "all these amazing species that are essentially going down the drain". Because at this point it was unclear what he meant by biodiversity, I took advantage of a scenario in which Hamish needed to use his definition of biodiversity to request he verbalise that definition. Hamish was shown an image of an old coal plant (Appendix A.3) referred to as "this image" in the dialogue in Figure 3.2, and then asked to identify any biodiversity in the image, at which time I refused to offer a definition for him. When placed on the spot, so to speak, Hamish is able to put together a definition that is fairly coherent, if a bit confused in certain places. His BTEC curriculum does not include any instruction in ecology (BTEC, 2016) and so Hamish must instead draw on material from the Challenge project alone[25]. While he said he very quickly determined that the Biodiversity pamphlet he was provided was not going to be of much use, his definition above bears some resemblance to the material in the pamphlet (Figure 3.2).

- R: Okay um and do you see any evidence of biodiversity in this image?
- H: Define 'biodiversity'
- R: That's the point
- H: That's the question
- R: As you think of biodiversity because you were already talking about it so in your mind what your image of biodiversity is, is there any evidence of this here?
- H: Okay umm well my idea I don't actually know the definition of biodiversity I've been fairly winging it halfway through um I do that a lot but yeah my my idea of biodiversity is simply the diver- or the range of um species/ well yeah mainly species whether you're talking about organisms or plant life the range of which you have in a certain environment that that would be my assumption as to what it is um

Figure 3.2. Hamish's definition of biodiversity on 18.03.23 (left) and the definition available to him in the Anglian Water Biodiversity strategy pamphlet (Anglian Water, nd) reprinted with permission

[25] It is recognised and accepted that Hamish may have been exposed to biodiversity during his GCSE studies; however, the assumption is being made that he is primarily drawing on new information. This is supported by later statements regarding his understanding of biodiversity prior to the start of the project.

There are a number of interesting points in this definition. The first is Hamish's use of the term 'species'. Given that there is no clear consensus as to the exact definition of a species, it would be difficult to argue that his conception is entirely inaccurate, but when Hamish suggests that biodiversity is "mainly species", it does raise some interesting questions as to what is included in his definitions of species, beyond the "organisms or plant life" he specifically mentions above. He also suggests that plants are not organisms, but may be included are species. There was not time to pursue this idea in that session, but it was brought up the following Monday (16.03.26 lns 20-32), when Hamish was happy to elaborate.

> R: Alright and then you actually already mentioned the other two uh one of them is 'organisms' so what counts as an organism?
>
> Hs: Um well you've got the whole MRS GREN thing that I can't actually remember but that's how you define an organism um and so that if it follows along to those sort of statements I can't remember for the life of me what they were I haven't done them since Year 7
>
> R: Do you remember any of them or?
>
> Hs: [incomprehensible sounds of thinking] what was it something like it was MRS GREN and it was ahh movement respiration maybe movement respiration uh something something something something something I can't actually remember but I just remember that um if a creature or if a thing um was subject to each of those things then it it was defined as an organism um but then you also have like I'm thinking of the specific species uh as well so um I wouldn't define like a tree or something as an organism I'd define something which again effectively just repeating myself abides by the whole MRS GREN statement

Despite not being able to recall every criterion from the acronym MRS GREN (movement, respiration, sensitivity, growth, reproduction, excretion, nutrition), Hamish is willing to accept that anything that satisfies these criteria qualifies as an organism and therefore as a component of biodiversity. There is some risk that, because Hamish's recollection of the criteria is incomplete, he might fail to exclude something that fulfils the criteria he is aware of, but does not meet the

remaining ones. An example of this might be the relatively common misconception among students that viruses are living things (Simon, Enzinger, & Fink, 2017). Of more immediate concern is Hamish's lack of understanding about the nature of movement, which led him to view plants as non-organisms, though he still counts them as factors in determining biodiversity. His version of MRS GREN also carries through to his definition of species (18.03.26 lns 35-40):

> Hs: Uh so anything any group of um I I want to try and make this as vague as possible cause that's effectively what species are um eh any group of you know mammals vertebrates invertebrates yada yada yada um that share common traits I suppose that would be one that would be sort of how I define them so there's no there's no major difference between them there is a common thing linking them all together and that is you know their movement, their well effectively the whole MRS GREN thing how they do each of those

In much the same way that early taxonomies of organisms were developed without awareness of genetics, Hamish relies on readily observable characteristics to differentiate between species. This also creates a contradiction, as he does acknowledge that different species of plants exist which would imply that they are indeed able to fulfil all criteria of MRS GREN. Hamish was able to avoid having to address this contradiction on any meaningful level by suggesting that both organisms and plants contribute to biodiversity. In a statement following up on his definition of species above, Hamish again repeats a definition of biodiversity (seen in Figure 3.2 above) which includes "the difference or the range in um species that you find in a certain environment" which makes less attempt to exemplify the term species, and thus is more open-ended and flexible.

What had not at this point come up was how Hamish viewed the environment itself; what role did the abiotic factors, or even biotic factors that did not fit within Hamish's conception of an organism or species, play in biodiversity? Hamish, ever proficient at anticipating segues in our conversations, followed up the recapitulation of his ideas regarding biodiversity with a further clarification (18.03.26 lns 71-76):

> Hs: …if you focus on a certain it depends on how big or small you want to sort of go into if you look at like a certain area you'd say the different wildlife you've got in there has got quite a high biodiversity in the area just because of the amount of different um habitats that they have set up there um if you wanted to look more in-depth at one of those specific environments you say well it's quite biodiverse in all of the species and organisms that it has in that environment so yeah

While Hamish quickly clarifies that the *actual* biodiversity of a given environment does not change based on the level at which it is being studied, the criteria for diversity may change. In a national park or game reserve, the number of unique habitats may be mentioned as an indicator of overall biodiversity; an examination of a single example of those habitats would not consider this and would instead focus on the individual "species and organisms" within that specific habitat, or even microhabitat. At that level, the environment itself is given little consideration, with the focus "more on type of different molecular organisms [sic] you have" present. Disregarding for the present the apparent misspeak (he uses the term microorganisms in similar contexts both before and after this moment), Hamish again seems to indicate that there are two separate components of biodiversity: the "organisms and species" and the habitats in which they reside. Once the habitat becomes specific enough, it is only the organisms (and species) within that space that need to be accounted for.

These ideas of Hamish's were certainly at times contradictory and confused. However, a combination of his absence from the following Challenge day and the half term break meant that he had three weeks away to reflect prior to our next meeting. He admitted that he had given little active thought to the Challenge project while he was away, but had found that he had taken more note of some of the topics brought up during Challenge, including biodiversity. This meant the timing was right to attempt to elicit more detailed and perhaps coherent accounts of certain of Hamish's conceptions, particularly related to biodiversity and its constituent components. To this end, I made use of a modified form of Kelly's construct repertory test to elicit a more coherent description of some of Hamish's conceptions[26] of biodiversity, wildlife, plants, and

[26] The choice to not include organism and species was a deliberate one; because Hamish had most frequently associated animals with the former and both plants and animals with the latter, they were chosen to see if Hamish again made that categorisation without seeing the terms 'organism' or 'species'.

animals (18.04.16) with the overall results found in Appendix B.2. When Hamish was presented with 'animals', 'wildlife', and 'biodiversity' for example, Hamish offered the following justification (lns 119-121):

> Hs: … animals get their habitats from the wildlife
>
> R: Okay
>
> Hs: Although biodiversity kind of encompasses all of them…

This first quote offers several interesting points. The first is that at this point, Hamish felt that in terms of scope, biodiversity is an overarching idea, that can include both animals and wildlife. The second, which supports the first, is that Hamish believes that wildlife forms the habitats in which the animals live. This in turn supports other statements made by Hamish which suggest he considers wildlife to be more closely associated with plants, though "wildlife is much more general than just specifically plants" (18.04.16 lns 127-128). This is not inconsistent with the accepted definition of wildlife (Usher, 1986) but is somewhat surprising given much of what Hamish might have been exposed to in his daily life associates wildlife with animals, and indeed with his use of the term on the 9th of March[27]. Finally, biodiversity encompasses both of these separate groups, as has been stated previously.

This coherence Hamish seems to be developing becomes a bit more complicated when instead of 'Hamish is presented with 'plants', 'habitats' and 'biodiversity' (18.04.16 lns 279-284):

> Hs: …it's quite literally in the name you have a diversity of the different biology of the area meaning plants, animals, whatever … certainty the title habitat encompasses a lot of pieces of information so you know um environment, species that live there, conditions of it and biodiversity is also encompasses a lot of different information

[27] Hamish's use of the term wildlife to refer primarily to plants is much more enduring than his use of the term to imply animals. As discussed at the beginning of the chapter, Hamish is often inclined to select the first word that comes to him, and so on-off contradictions are hard to interpret as conflicting conceptions

It is clear that Hamish's perspective on biodiversity is at this point fairly consistent; it contains all the living things within a given area. It is the way in which he creates sub-categories for these living things which tends to vary depending on what he is asked to describe. Habitats are, as he said previously, more than just plants and here he elaborates upon this by providing three components: environment, species that live there, and the conditions of it. What is unclear is where wildlife, which Hamish has acknowledged is more than just plants but does provide habitats for animals, fit in exactly. If as before Hamish still sees plants as separate from organisms (and therefore theoretically from species), they may be considered part of either the living habitat or the non-living conditions. What is interesting in this instance is that Hamish is much more broad in terms of his definition of biodiversity, this time referring to the "diversity of different biology", which he then leaves open ended. By doing so, he limits himself less than in previous instances by accounting for organisms he has not yet considered; in a follow up statement, Hamish makes clear he does not necessarily believe all microorganisms are animals for example. His previous definitions may then have excluded them from biodiversity, but this updated understanding allows for them under the "whatever" category mentioned in the quote above.

After this session the results table (Appendix B.2), along with Hamish's justifications for each decision, were examined, and it became clear that the connections presented would form a network of some kind. It seemed an ideal opportunity to build a map of Hamish's thoughts, and this concept map (Figure 3.3) was the result, using only the connections Hamish made, and links were annotated using his justifications. What was revealed is that Hamish essentially had two distinct categories for the concepts he has been engaged in building, as can be seen in the map itself. Hamish himself was quite surprised by how accurate he found the map when it was presented to him on 18.04.23. He did not feel as though 'microorganisms' was the natural link between the left and right sides however; he felt that if anything, decay was a more appropriate link. This is because in his view, most of what happens on the left leads to decay, which would impact the biodiversity of an ecosystem "what happens over here affects what happens here very much so" (18.04.23 lns 271-272) and decay is something that could happen to environments and what is in them. This is the first concrete example of Hamish raising concern about the impacts of human activity on biodiversity.

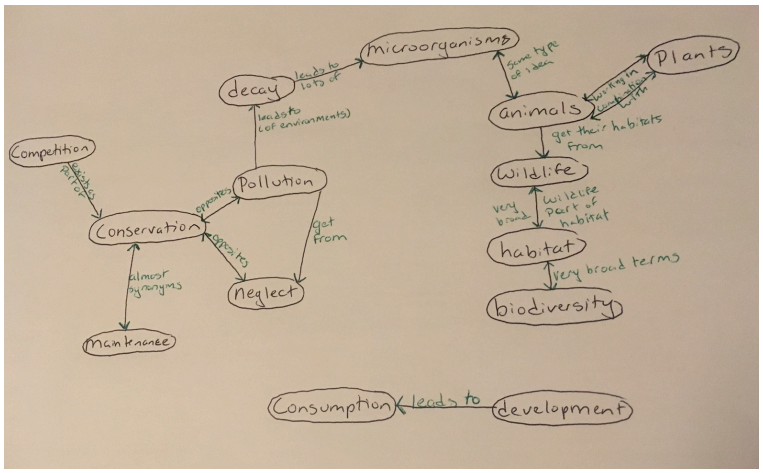

Figure 3.3. Concept map generated from the 18.04.16 interview using a triads card deck of common terminology, reviewed on 18.04.23

Because this session took place after a Challenge session actively considering biological indicators in the Nine Wells ecosystem (see Appendix A), a discussion of that had taken place just prior to Hamish seeing the concept map. In this session, I asked Hamish to identify several specimens taken from the field trip, and we held a discussion of their role in indicating the presence or absence of impurities. For this reason, Hamish's attention may have been already turned towards cause and effect, but because that had also been the focus of the previous Challenge, it is hard to state with any certainty that our conversation had any direct impact. Futures sessions make clear, in fact, that this awareness is a continuing one.

While Hamish's focus shifts between water management (and its impact on humans) and biodiversity over the following weeks, generally following a Challenge focussed on one or the other, neither is completely abandoned. In our final interview before the Primary day, Hamish makes it clear that the human needs and the environmental needs are closely connected (18.05.14 lns 36-40)

> Hs:…conserving water is very important umm just for the fact of the way it's destroying local habitats just by completely not having as big a regard as we should for the natural environments um for the simple fact that if we keep up taking water at this rate we're not going to be able to continue development of the surrounding areas…

Here Hamish's concerns about the destruction of the natural environment and his concerns about the sustainability of urban development merge, as he reveals what he believes to be a link between the two. Even if not conserving the natural environment for the sake of biodiversity, we benefit from conserving biodiversity and the local environment because it makes the drawing up of resources more sustainable for urban development. It is a statement vague enough to be considered either accurate or inaccurate, but shows that Hamish believes that in order to make use of the surrounding environment, humans must maintain it as well. This is one of the most direct links seen in any of our meetings between the human process and the natural outcome, and is consistent with his previous statements regarding cause and effect. It is also one of the few times in the later sessions where Hamish uses development to mean urban development, having predominately used the term to indicate the sort of developments aimed at enhancing the natural environment. This is indicative of Hamish's shifting focus from the human to the natural, as a result of his experiences. Indeed, this focus was made explicit when I asked Hamish to identify the primary theme of the project, as seen at the beginning of this section.

Despite Hamish's experiences and preparation for a human-centred activity, he remains convinced that the overall point of the project was to understand how humans were able to influence the biodiversity of the ecosystems around them. His musings earlier, about human actions feeding in to the natural elements of an environment, culminated in this expression of belief. While Hamish had previously made statements spontaneously, this one he was able to provide support for, suggesting he had been considering this for some time. For this reason, we dedicated the majority of our last session together trying to unpack Hamish's conception of biodiversity (18.06.11 lns 21-27):

> Hs: Oh flip I don't know if I could give a sentence definition of it um just I I haven't thought enough about it or anything um but it encompasses it's a word that describes and encompasses um the variation in different organisms, plant life, um and habitats that will come under either a certain area or a set piece of land or something like that or it can get more specific like biodiversity doesn't necessarily describe a specific habitat it could describe a group of habitats it could be really specific it could be just one area of a habitat but it it's used to describe the variation and the different yeah different numbers or organisms and plant life

Certain elements, such as the idea that plants are not organisms, have persisted throughout the Challenge project. This is perhaps unsurprising; little was done concerning plant life, with the biotic focus being on the aquatic invertebrates that could be used to indicate water quality. However, certain elements of his definition of biodiversity have become more sophisticated, such as the expressed belief that "the word biodiversity doesn't necessarily have to give an explanation for what its findings are it just gives what they are" (18.06.11 lns 36-37), suggesting it is on the human observer to determine these explanations, and that regarding any critical component of a diverse ecosystem "the thing that makes it a key factor is that it's there, not necessarily that it interacts with the other ones although it does". Hamish's final conception of biodiversity is more of an accounting of the elements present, rather than a narrative of how they interact or an explanation for their presence. This does not mean that biodiversity is merely a number on paper, however (18.06.11 lns 148-151):

> Hs: …biodiversity explains how um an ecosystem is able to uh keep on well living I suppose well whether it's decreasing in number or increasing in whatever it's simply how it works so all the different factors that mean it can sustainably grow

The excerpt, from Hamish's final thoughts on how his views of biodiversity have changed over the project (Appendix B.3) show that while biodiversity needs no explanation, it is ready to provide one. Biodiversity is not only an indicator of the health of an ecosystem, it is the means by which the ecosystem is able to stay healthy and to sustainably grow. Hamish seems to accept that biodiversity leading to sustainability is a natural phenomenon (Watts & Taber, 1996) and thus does not consider *why* biodiversity explains the continued existence of an ecosystem, but he is undeniably considering with greater care than before the factors that influence ecological health. From the early weeks when Hamish asked me to provide him a definition of biodiversity before he identified examples of it, his conceptions grew and changed into the decisive answer he was able to give here. While this final definition was given only three weeks following the conclusion of the project, it lost little of its complexity, and indeed Hamish provided more detail in the 06.11 interview than he had elsewhere. This gives some hope that Hamish has been able

to develop this understanding sustainably, and like the biodiversity on Nine Wells, allow it to grow.

CHAPTER 4- Hamish's engagement

4.1. Hamish's engagement with the water management project

While one of the primary purposes of this case study was to determine whether or not learning took place in terms of content knowledge, there exist multiple types of learning (Fink, 2013; Taber, 2014), and an examination of some of these both in their own right and in consideration of their impact on the learning of content is worth conducting. Because it has already been established that students who are engaged are more likely to experience cognitive change (Dole & Sinatra, 1998, Pintrich, Marx, & Boyle, 1993), an examination of Hamish's engagement and the factors that influence it is worthy of consideration. Existing research (Nadelson, Heddy, Jones, Taasoobshirazi & Johnson (2018); Pintrich et al.,1993) suggests that there are relationships between positive emotions towards the subject, engagement, and conceptual change, which means that, as seen in Fink's (2013) overlapping types of learning (Figure 4.1), elements of engagement (Appendix C.2.b) are not only learning in their own right, they also overlap with and impact learning in other area, such as content knowledge.

While it would be possible to follow numerous of aspects relating to engagement, three areas will be looked at here. These are self-directed learning, developing new feelings, and developing new interests. These each represent an aspect of Fink's Significant Learning, but may also be seen as examples of emotional and behavioural engagement (Sinatra et al., 2015).

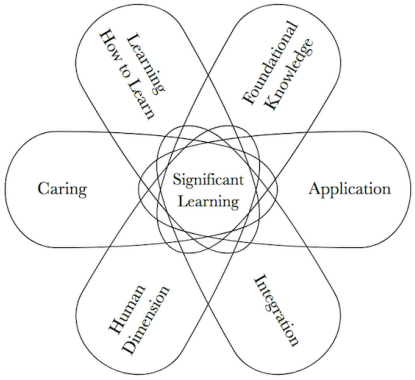

Figure 4.1. The interactive nature of significant learning, as seen in Fink (2013). Reprinted with permission

While learning and significant learning have both been given attention in the review of existing literature, it is worth considering each of these selected elements in greater detail here so as to understand Hamish's experiences and their consequences.

4.1.1. Self-directed learning

Given that the core principles of constructivism posit that the learner internally constructs their own meaning from a given experience, with reference to their own prior experiences, the development of self-directed learning ability is critical. Self-directed learning was also an aspect of the first teaching objective of the project (Appendix A.1) where students had to plan ahead effectively to remain productive should group members be absent. As in many cases it was Hamish who was absent, his task then was to ensure he had not fallen behind the group and was able to be of use when present. There are few if any examples of Hamish taking the initiative to catch himself up (indeed, there were times when he explicitly and almost pridefully acknowledged he had not caught up on the missed work, particularly when it was not a topic of interest to him). What was far more common was evidence of and preference for self-directed learning during Challenge sessions where Hamish was present and expressing either positive emotions relating to the topic or a strong positive self-efficacy. Phrased differently, when Hamish felt he either had the tools to self-regulate and self-direct, or when he felt guided learning insufficient to cover the topic, he was quick to plan a research programme for himself and his team. The Challenge session on the 21st of March provided a prime example of this, with two very different activities. The first was the interpretation of weather data, about which Hamish was decidedly less than positive (18.03.23 lns 8-15):

> Hs: …the problem with us is we're given all of this us relevant set of data which to took us flipping ages to format but um then once we'd done that we weren't given enough guidance to then go on to find cause we were meant to be comparing the um the weather here with the standard of the terrain along the um Hobson's Conduit and we couldn't find anywhere where to get this kind of information for um Hobson's Conduit for what the general conditions of it were on these days and then to compare that with the weather so

> we understood what we were meant to do we just couldn't get there cause we didn't have the right resources or we couldn't find them

Hamish's group was given sufficient data from the weather monitoring station on site (Appendix A.4), but Hamish felt that they were not given enough information regarding the goal, or sufficient guidance on accessing resources. Because Hamish did not feel he was adequately aware of the end goal or related success criteria, he was not as self-directed or self-regulated in the activity (Perry, 1998) and lacked any level of intrinsic motivation to succeed, being content merely to copy the data table, which did not make it into the team's final report anyway. He was not unwilling to consider the impacts of weather on the Nine Wells site; our interview produced several attempts to predict conditions based on weather patterns, and even explanations for certain phenomena. Rather, because he felt he was unaware of his target, he was unwilling to take risks with his learning (Perry, 1998) within the classroom setting.

If we contrast this with the afternoon session, some differences become immediately apparent. In this instance, Hamish was specifically aware of the aim (to link local conservation to biodiversity) but experienced strongly negative emotions relating to the provided resources (18.03.23 lns 106-119):

> Hs: Umm well firstly I think this was just a minor point and I don't know how much this affected other people but it was more just the fact the way it was laid out it looked like it was laid out for 5-year-olds …at the moment we have to read medical journals for some of our coursework so we're dealing with very kind of sophisticated kind of out of our league stuff so we're used to dealing with all this other stuff and when we're given a piece of material that is quite clearly or looks to be aimed at um a younger learning age you kind of get put off by it … if it gives you information you should just read the damn thing um but yeah you kind of feel superior when looking at it and you think I looking at this I don't think this will give me any relevant information kind of the key skills we're taught of this year is to sort of be able to skim something and see where the relevant information is

Hamish's strong emotions in this instance came from a strong task-related self-efficacy, where he felt that due to his reported BTEC experiences with research in more academic sources, this publicly available pamphlet (Figure 3.2) appeared to be childish in design, and Hamish disengaged because he felt it was not a suitable resource. Because he felt compelled to complete the research task set for him however, he and his team set about doing independent research on biodiversity via Google, where they were able to "make general sort of predicted links as to why um Anglia Water or whatever it was called um might uh be changing their plans or might have certain ideas for uh plans they have" based on their own research and on their previous instruction on the topic.

Perhaps the best example of self-directed learning however came immediately before the Primary day, which Hamish had been anticipating greatly. Having been given, in his mind, a clear and appropriate goal and sufficient guidance and skills to access resources to meet the goal, Hamish was actively involved in and enthused by all of the preparation necessary to set up an interactive activity related to flow deflectors. He was given the choice from among three options, and then his group was provided materials and an open-ended goal for the structure of the activity. It was clear the lack of prescribed activity was able to trigger their creativity; several quite different iterations of the final product were proposed before the team determined the most realistic and engaging scenario for the students. This selection process was quite engaged, with the team proposing and discussing ideas before doing internet searches to support their plans.

Early on, the group realised their direct instruction on flow deflectors had been limited, and therefore engaged in independent research to learn more. That research fairly quickly turned up the idea of using natural materials in the deflectors, which was one they chose to carry through. Multiple set-ups were then considered, including asking students to design a way to clear debris (placed by Hamish or his teammates) from the gutter using only a select set of materials. The group actively discussed the pros and cons of each model before eventually deciding to provide the Primary students with a variety of raw natural materials such as sticks, rocks, and leaves as well as Plasticine and a gutter. The goal would then be to select and place materials such that they would produce the maximum flow rate given a certain slope to the gutter and a set volume of water.

The risks the group took here, as well as the variety of sources they consulted, was much higher than in previous sessions, where the team was more inclined to rely on the instructor or on classmates for assistance. Hamish explained the difference by stating that "when you have to communicate this information to other people that's when you sort of uh start becoming a little bit more engaged in the whole um the whole activity and the whole research uh task" because the consequences for lack of attention fall not only on the one who failed to complete the task, but on a whole other group of individuals, in this case the Primary students. In this instance, this combination of altruistic motivation and project autonomy led Hamish to pursue varied topics, such as volumetric flow rate equations and the natural impacts of the flow deflectors. The team was also to appropriately pace themselves and determine an appropriate runtime for the activity, so that on the day it was as seamless as is reasonable to have expected. A few Primary teams were disappointed with their results, and at times Hamish had some difficulty in keeping the students on-task, but in general he felt as if the day ran smoothly and the Primary students left with at least an overview of stream ecology and water management. Hamish's reaction to having completed the task was as positive as his predictions (18.05.18 lns 362-364):

> Hs:…it was quite interesting the way we had to sort of take our knowledge of the situation think 'right how can we make this simpler while also keeping why it's important present' so yeah we had to think about that quite a lot

In this instance, Hamish's emotional, cognitive, and behavioural engagement (Sinatra et al., 2015) was increased through the instructor's stratagem of placing Hamish and his team in control of the day's activities and allowing them to direct and control their own learning.

4.1.2. Developing new values

Developing new values, interests, and feelings, particularly positive ones, was important for Hamish because "if I don't find a subject interesting, I don't really get motivated to learn about it" (18.03.02). Unlike Hamish's subject knowledge, which generally increased as the Challenge went on, the development of new feelings, being interpreted as changes to his attitudes relating to a particular topic, tended to be more fleeting and situational, as Hamish himself pointed out: (18.03.09 lns 170-175:

> Hs:…I'm quite easy to sway based on the environment I'm in and so at the moment the environment I was in with him [speaker] was he was giving this great passionate good speech about why we should save this [Nine Wells] and I got to the end and I was like 'I'm totally with this guy has completely got my support, I'm going to go home and research this' and then the other lady got up and she started talking she's like 'it's not that I don't care about this but I also have these other priorities on my plate' at which point I was able to be like 'oh. Okay right'

There are significant implications for this in terms of analysis; Hamish's attitudes towards a particular area are often situational, and will shift depending on context (in all fairness, this cannot be attributed exclusively to Hamish). This is less evident in areas where Hamish came in with pre-formed values, such as with biodiversity. Because Hamish already had an (admittedly vague) understanding of biodiversity as a positive aspect of environmental health, his increasingly complex understanding of it did not shift his feelings measurably. Areas where Hamish was more conflicted, such as development, showed much larger changes, due in part to Hamish's dual interpretation of development (as a rough synonym for conservation, and as urban development).

Even when Hamish was relying on a single definition of development, usually in the urban sense, there is some conflict with regard to his feelings (18.03.12 lns 92-96):

> Hs:…by further developing the area I think in one sense you think 'okay this is good the whole urbanisation we're expanding the city we're allowing allowing more companies to come in settle here' which is certainly something we need during Brexit and everything um but we are allowing for the space of all of this to happen for companies but we're turning a sort of blind eye in a sense to the uh to the environment…

In these early stages, Hamish is drawing upon his prior knowledge to make judgements (Brexit, for example, had not been extensively discussed as a factor in the expansion of the biomedical campus), but the presentations on the first day of the project clearly impressed upon him the importance of green areas in the greater Cambridge area. He provides a list of benefits including recreation and mental health, and so while he sees the financial need to expand, Hamish feels it

should not be done at the expense of the natural environment. For several weeks, his views that development can exist only at the expense of the natural environment persist, making clear his conception of urbanisation as an 'either-or' situation with regards to local green spaces.

By mid-March, Hamish admitted there was a possibility that human interaction with the environment may be positive: "well I say 'human intervention' I'm specifically referring to bad human intervention because obviously we can do stuff to improve the flow of it and that would be more of a better human inter-something or other" (18.03.19 lns 24-26). This does not necessarily change his views on development, but does mean his mind was receptive to the possibility. After the Challenge session on weather data, Hamish began to integrate some human interventions into his conception of conservation, such as devices to prevent runoff or flooding, or to increase flow rate[28] should there be insufficient water. Indeed, when shown a picture of a dam (Appendix A.5), his immediate response was that the device was meant to regulate the flow rate of the river and prevent damage to the surrounding environment. At the same time, he viewed the urban landscape around the dam as his primary example of pollution, so there was clearly a limit to the benefits human structures could provide.

Another major shift comes after Hamish is able to visit the water treatment plant. This field trip was meant to include a trip to a rainwater recycling facility but due to construction issues (the facility is part of a growing sustainable development in the Northwest portion of the city), they were only informed of the facility and its purpose. From this description Hamish took a neutral view on development for the first time. While previously he had expressed both positive and negative views on development, this was the first time he expressed a more neutral view, suggesting that by developing sustainably, it was possible to have minimal impact on the natural environment. From this point, his perspective tends to be more positive relating to urban developments, so long as there is controlled use of local resources "you could link conservation to development in certain situations in the sense of um if we want to keep uh something running effectively you'll want to conserve it" (18.04.16 lns 224-226). As he completed the project itself and began to consider the Challenge from a reflective perspective (18.05.14 lns 273-278):

[28] Flow deflectors were not mentioned at this point by Hamish, though they had at least walked by them on their creek walk days

> Hs:…it's not a matter of right and wrong even thinking now development of urban structures doesn't necessarily mean bad for the environment such as all of these these well talking about runoff again it's we we have well not me but um uh we have placed uh barriers and stuff stopping the um runoff from farms going in to the Nine Wells we have placed placed um all these things so development of urban structures doesn't necessarily mean a negative impact on the environment

In this situation, Hamish views the artificial barriers built to prevent runoff from local agricultural land as a sort of balancing act, taking the theme of the project (water management) and acknowledging that this tremendously complex issue can only be considered via a compromise between natural ecological development, and urban development necessary for economic growth of the Cambridgeshire area.

4.1.3. Developing new interests

As Hamish admitted to me in our first meeting, his preferred learning style tends towards the "but why" approach, where he will repeatedly ask for explanations to new phenomena, often to the point of being told he needs to abandon his inquiries because there is no time budgeted to answer anything in excess of the syllabus. If he already finds a topic interesting, he has the motivation to learn more about it, but not every topic is interesting to him right away. He was fairly self-aware about his academic interests and how they developed, however (18.03.09 lns 11-17):

> Hs:…it's not necessarily a fact of whether I relate to it or not because I find um stuff like oh I don't know natural disasters very interesting and learning how they happen how it's dealt with and stuff like this but of course that barely relates to me at all and so I think there's definitely a natural curiosity there that's just random I think it's safe to say um I think it is possible to make a subject that I look at from the start and I think uhhh that's kind of you know I'm on the fence about it, I think learning a little more about it can sort of kick start the curiosity…

Ecology had never been a primary interest of Hamish's prior to this Challenge, and as mentioned before, the project was not his first choice. Ecology does not relate to his future career prospects to any significant degree, it is not as independently gripping as a large-scale disaster might be to him, and he had little prior direct exposure to the topic. Based on his statement above, however, there was a reasonable chance that as he learned more about the topic, he would gain a greater interest. Because Hamish had previously expressed the belief that he was only going to be motivated to pursue a topic if he was interested in it, there was therefore potential for the development of a positive feedback loop within this Challenge. Because I have already explored how Hamish's conceptions of biodiversity changed over the course of the project, it makes sense to explore how his interest in the topic changed with his conceptions.

Looking back at the pre-Challenge interview, Hamish has no real knowledge or interest relating to biodiversity, at least none that he understands as biodiversity. As was seen in later weeks, he had foundational knowledge from other classes that related to the topic, but only in very specific ways. A prime early example was his attempt to apply Le Châtelier's principle to the disruption of local ecology (at the time biodiversity was not mentioned) in the form of an invasive species. Beyond this, he was quite vague and dismissive of the role of food webs, for example, in almost throwaway comments. The first example of Hamish showing real interest in the impacts of biodiversity loss was after the first Challenge session, where he admitted to being quite drawn in by the enthusiasm of the speakers. Taking on the theme of habitat loss having a major impact on the local or global populations, Hamish draws again on prior knowledge to corroborate the warnings he heard in the lecture (18.03.12 lns 75-78):

> Hs:…like I'm thinking back to my Year 9 Geography project on it it was it was some amazing figures like it holds 80% don't don't hold me to these but it was like 80% of the world's wildlife generates a ridiculous amount of the world's oxygen the figures the facts and figures go on but it's we're taking all of this away that's going to have an effect

Hamish is still quite vague, "that's going to have an effect", but he took away a sense of urgency from his first Challenge session, and the animation with which he predicted dire consequences for continued habitat destruction indicated he had at least started to have an interest in biodiversity loss and its impacts, if still on a larger scale than the Nine Wells area. He admitted

that his enthusiasm for "worms in holes" in the specific Nine Wells ecosystem was driven mainly by the speaker's enthusiasm for the subject, and after the infectious enthusiasm had waned, Hamish put them out of his mind, suggesting it was not a lasting change.

Hamish's interest and enthusiasm for the Nine Wells site dimmed after his initial visit; a combination of winter conditions, overgrown plants, and indeed his own idealised mental image of the site meant that what he saw was underwhelming. At this point, he was less concerned about biodiversity for biodiversity's sake, but did pick up on more of the more obvious consequences on a broader scale. Two particular examples from our post-visit interview jump to mind: reduced outflow and its impact on the water cycle, and the use of the Nine Wells/ Hobson's Creek ecosystem as a recreation area. In terms of downstream impact, should the aquifer that feeds Nine Wells be completely depleted, Hamish was quite vague. He acknowledged this and admitted he had little knowledge in the area, but it was not a particularly engaging part of the discussion. The impact on leisure activities of the local human populace he had much more to say on (18.03.16 lns 226-229):

> Hs:…I mean yeah you kind of are disrupting the wildlife out of their natural habit but you're also allowing people appreciation of the space and you're allowing them to get an interaction with the environment at a much closer level which I think is very important to be able to really appreciate what it does give you…

In the midst of a discussion about the management of the Nine Wells area and what role human recreation plays, Hamish initiated a discussion about how using the site for human enjoyment may actually prove beneficial for the ecosystem as a whole, which is the first time he had volunteered a direct interest in the ecological health and thus the biodiversity of the Nine Wells site (in this instance, specifically the number of fish species present for fly fishing). While still primarily anthropocentric in his motivations, Hamish has begun to consider how what benefits him (or other humans) may also benefit the Nine Wells ecosystem.

Hamish's anthropocentric views on the importance of biodiversity continue for some time. Exploring beyond his assertion that biodiversity "is our future, isn't it" (18.03.23), Hamish recognises that it is a selfish way to view the situation, but a decrease in biodiversity will mean a more difficult time for humans when it comes to extracting desirable natural resources. He is at

this point interested and invested in biodiversity for humanity's sake, but recognises that he *should* be concerned about biodiversity for its own sake as well. He does at this time acknowledge that "all these amazing species that are essentially going down the drain" though again his emphasis is still on what this means for humanity. There is a shift after the water treatment plant trip, however; as seen above when Hamish begins to think positively about development in situations where those developments protect or enhance biodiversity, suggesting it has value to him.

Hamish never did develop sufficient interest to motivate him to do any independent investigations beyond those necessary to complete his assigned tasks, but he did begin to connect ideas from across the project. In particular, he began to integrate his conception of biodiversity, or variety at least, into all of our conversations. In the final interview before the Primary Day, Hamish and I were discussing the way he viewed certain terms and from the start he warned me that most of these would connect to the Nine Wells site because it was something he was considering at the moment, and that Nine Wells theme shifted into comparing different habitats (part of Hamish's conception of biodiversity) and presenting examples through this filter (18.05.14 lns 333-339):

> R: Give me some examples of animals
>
> Hs: Well I mean if we're taking it's quite obvious but if you're taking an example of a river and a field you're obviously not going to find fish flapping about in a field … in normal circumstances if Sharknado[29] hasn't just happened you won't find fish flapping around in fields but yeah just I mean it's the way different species flourish in different conditions so you're going to be finding a lot more insects and stuff like that around well to be fair I suppose you'll find that in both of them um but yeah yeah

While Hamish does not exactly answer the question as expected, this exchange suggests that Hamish's conception of animals now includes characteristics such as their environments, or their interactions with them. While it would be easy to disregard this particular moment as a whimsical way to inject humour into an interview that had already gone on for quite some time

[29] Sharknado is a 2013 science fiction film about a series of shark-infested tornados in Los Angeles

(this particular interview ran approximately 40% longer than average), it does show that Hamish had by the end of the project taken into his understanding of ecology that diversity may include or even be dependent on the habitat, and that it is those conditions that determine the success of different species. It is at the end of this interview that he declares the real focus of the project was not water management, but biodiversity and how human actions might impact that.

4.2. Impact of instruction

It has been established previously that when students are engaged and/or motivated, it is more likely that learning will take place. This is true whether speaking of a conceptual change (Dole & Sinatra, 1998) or a change in behavioural potential or emotional capacity (Fink, 2013). Because of this, a consideration of the course structure is vital in determining which aspects of this project-based instruction had an impact on Hamish's ability to learn. This task was seemingly quite simple with Hamish, as he was not shy about expressing his frustrations when he felt they were justified, which was seemingly most of the time. He was also quite explicit about aspects of the project he found enjoyable. It would be foolish to rely exclusively on Hamish's self-reports, however. It is a common enough occurrence in the classroom that a student who believes themselves disengaged will in fact retain learning from that lesson and show evidence of that learning in other situations. This happened several times to Hamish, though he was in most situations accurate in his assessment. Here, I will be revisiting several instances of Hamish's learning, and relating these to the instructional methods of the lesson surrounding the learning, as well as Hamish's explicit attitudes about them.

4.2.1 Impact of lessons on Hamish's conception of biodiversity

The first Challenge day featured three speakers: two who would most accurately be described as representing the interests of Nine Wells as a natural site, while the third represented human interests in the area, specifically the water supply. From each of the speakers, Hamish took select pieces of information. The first, by Professor Emeritus Peter Landshoff of the University of Cambridge, had a noticeable impact on Hamish's idea of negative impacts on

biodiversity: it is from this presentation that Hamish heard the oft-repeated names of pennywort and hogweed, which became relatively common (5 and 7 mentions, respectively) examples of negative presence in the ecosystem. The term 'invasive species' itself was never explicitly used by Hamish, but he did pick up on the fact that plants where they do not 'belong' is a negative disturbance to an ecosystem, almost always accompanied by one or both of the specific examples offered to him in this first lecture. However, in the final session, Hamish offers up both pennywort and hogweed as 'riverbed plants' with no mention of their invasive nature (18.06.11 lns 340-347):

> Hs: So you'll get plants that are naturally more well they they'll develop in water so let's say the pennywort and the hogweed examples very much uh riverbed plants um you're not going to find those in the middle of an open field to my knowledge I don't know I don't know much about pennywort and hogweed um but no you'll be finding a lot more sort of different um plant species to that area so like um I I don't know daisies and weeds and stuff well you find weeds there but so daisies and stuff like this which will be different to the pennywort and hogweed the lily pads that you'll find along water beds and stuff

This does not necessarily mean he is accepting them as native species; every other mention of them carries a negative connotation. Rather, it is likely his ready use of these two examples is a sign of how much they have been prevalent in his consideration of the Nine Wells ecosystem.

As Hamish has previously been noted as saying, his attention tends to drop off after a certain period of time. It is perhaps not entirely unexpected that few specific examples from the subsequent lectures held on the initial day of the Challenge endured much past the first day. Hamish recalled, in our second interview, that he found the second speaker's enthusiasm for "worms in holes" (18.03.09) quite infectious at the time, and he did after this exhibit a belief that microorganisms have value to the ecosystem (an idea presented in the second presentation), but he was less likely to attempt to quote this second presentation than he was the first. The final activity of this first Challenge day was more interactive, a panel discussion in which the students discussed important issues relating to water management with one another. Hamish on several occasions made points about sustainability and balance, two themes that did occur with

reasonable frequency throughout the remainder of the project. Hamish on several occasions discussed what he perceived as a need for the public to have a connection, emotional or otherwise, to the natural environment as a way of encouraging them to conserve its resources (the previously mentioned pleasure seekers (18.03.16) being a prime example of this).

This first day seemed to establish a trend; if Hamish was being asked to participate in some way, he was likely to take on elements of the lesson into his conception of biodiversity. Another early example was during Hamish's first direct exposure to Nine Wells and Hobson's Creek (18.03.16 lns 257-268):

> Hs: …as we followed the river down um what's it called Hobson's Conduit as we followed it down it went past a number of different allotments which is you know great for umm people in the urban environment to get uh what a feel for the environment but um but we found one of the major things is they kept using these that their own pesticides … doesn't mention anything about the water quality or how this might affect water quality so I think that's also something it's quite minor in comparison to these other things but I think it's a very important thing that you address this and you start thinking 'ah no we need to be um educating the consumers about what possible effects they are having here'

While Hamish had already been told that runoff pollution may be a factor influencing the ecosystem, he was able to form a more impassioned argument for education programmes to combat water pollution after seeing first-hand how close the allotments are to the stream, as well as some of the chemicals being used, and given time to consider their impacts to local wildlife. As in the example of pleasure seekers (particularly fishermen) above, Hamish is integrating the idea of compromise into his evaluation; the allotments generate pollutants, but they also allow people to "get…a feel for the environment" as well.

The following week involved formatting weather data and reading up on biodiversity; of all the Challenge days, Hamish showed the most explicit resistance to the lessons this day. Indeed, during the afternoon session, Hamish described the pamphlet (Anglian Water, nd) as "forced learning" and afterwards maintained that he skimmed the material just enough to determine it was beneath him and then moved on. As seen previously (Figure 3.2), Hamish still

managed in our follow-up interview to produce a definition quite similar to that offered by the pamphlet (though admittedly less inclusive). Two logical explanations for this exist: either Hamish read more of the pamphlet than he admitted even to himself, or he found another definition online, and they are all similar enough that any similarity with the offered material is purely coincidental. It is impossible to definitively commit to either conclusion here; Hamish's definition here was vague enough to have come from nearly any source, and indeed may be a result of background knowledge he himself was not explicitly aware he possessed.

More evidence exists to suggest that Hamish's later definition of biodiversity (18.06.11) was influenced by his experiences in the Challenge project. Most notably, his inclusion of different habitats (Appendix B.3) as both an indicator and influencer of biodiversity only emerged at the end of the course, reflecting his concerns that the increasing pollution along Hobson's Conduit was likely responsible for the decreased diversity of wildlife as the students moved along the creek; habitats were still a separate (if related) conception of Hamish's immediately prior to the kick sampling session, as also seen in Appendix B.3. In that same session (18.04.16), Hamish also expressed the opinion that "through pollution you have decay of environments, of species, etc., etc.", suggesting that impurities in the water may decrease biodiversity. While this session fell immediately after half-term break, the Challenge day immediate prior, for which Hamish had been absent, had been focussed on the abiotic factors, in particular the general quality of the water (O_2 levels, pH, nitrates, hardness, etc.). Again, there exists no conclusive evidence that any information related to Hamish by his group was responsible for this, and as he was absent, he was not given a chance to discover this connection through the project itself.

4.2.2. Early impact of lessons on Hamish's engagement

As suggested earlier, tracking the impact of instruction on Hamish's emotions and engagement was in some ways simpler than tracking its impact on his conceptions. There was little need to elicit Hamish's reports of this engagement; Hamish was unfailingly vocal in his attitudes towards a particular lesson or assignment. His behaviour within the Challenge sessions often mirrored his reports, with instances of Hamish being off task or not paying attention often greater in sessions he would later report to have been of little interest. There were several

instances where his self-report did not match what I had perceived to be disengagement; one day where Hamish had appeared quite unenthused he later reported he was actually experiencing a headache. For the majority of instances however, Hamish's self-reported engagement matched what I inferred from his observed behaviours within the Challenge sessions.

Early on it is established that Hamish feels engaged when he is able to be supported in his quest for deeper knowledge, but has often felt discouraged in pursing these channels in class "my teachers always got sick of me asking why all the time" (18.03.02). While he acknowledges this is primarily due to the time constraints placed upon the class by the necessity of covering all the material in the syllabus, it is very clear he resents this. Hamish feels that one of the benefits of the Challenge projects is that they do not have the same time constraints, being separate from the mandated curriculum and therefore offering different learning opportunities (18.03.02 lns 49-51):

> Hs:…these Challenge Projects are great in the respect of discovering more and doing a little bit more in-depth research than you would typically do in lessons because you get people coming in the subject field and they're always happy to talk about their work…

Right away, there is evidence to suggest that Hamish would be engaged by the expert speakers coming in to introduce the Challenge, and would value them as a resource on the subsequent days where they would be accompanying the students as they explored different elements of the site (Appendix A.1). Hamish's actions in the first Challenge support his view; when the floor was opened up to students to ask questions and contribute, Hamish immersed himself completely in the discussion. Two prime examples were the moment Hamish called upon his peers to remember they had to consider *projected* growth rather than just current population figures, and when Hamish first begins to insist that education is the only way to get the public to voluntarily conserve water without forcing them to do so. In these two moments where Hamish is able to rely on the support of experts and mentors, he is able to make connections and indeed make connections between realms of life (Fink, 2013) by analysing the current situation and planning viable solutions (Anderson et al., 2001).

The examples above may not at first seem like signs of engagement, and indeed they are perhaps better examples of a different type of learning than those I have associated with engagement (self-directed learning, developing new feelings, developing new interests).

However, it is the enthusiasm with which Hamish pursued this learning that indicated that, during this lesson, Hamish was able to develop new feelings and interests sufficient to develop his ideas. This was echoed in our follow-up interview two days following; Hamish admitted to being caught up in the enthusiasm of the second speaker and his passion for protecting the site completely, but then was also swayed by the representative of Anglian Water, who presented Hamish with the perspective of human necessities, leading to his belief that the best way to reconcile human consumption with conservation is to place no limits on the water, but to roll out an enhanced education programme that raises awareness to the point that consumers limit their water intake voluntarily. Because Hamish was exposed to both the consumption and conservation perspectives in class, his solutions carried elements of both.

The following week saw Hamish visit the Nine Wells site for the first time, where he and his group were responsible for taking photographs to create a catchment conceptualisation map (Appendix B.4, p.5). Hamish and his group largely relied on photographs taken by the other groups, as none of them took sufficient images themselves. Despite Hamish being unpleasantly surprised by the state of the site "…it was also well I a relatively sorry sight to be honest" (18.03.16), he did make a number of valid observations regarding the different factors that may influence ecological health as the stream went on. It was clear, however, that his image of a vibrant outpost of nature that would inspire large-scale conservation efforts had been shaken by the state of the site. However, in some ways it made Hamish even more protective; he was suddenly more concerned with noise and light pollution, as both could clearly penetrate the entire site given its size. Each subsequent visit to the site (Hamish was absent for one of them) was immediately followed by a renewed focus in Hamish's interviews on the organisms[30] present at the site, and what impacts other factors may have on them.

4.2.3 Later impacts of lessons on Hamish's Engagement

Perhaps of more interest were the activities that led to substantially reduced engagement, both in terms of lack of attention during and explicitly negative reviews afterward. It has been

[30] It has previously been established that Hamish's definition of an organism differs from the generally accepted use of the term. In this instance, 'organisms' is being used in the accepted scientific usage to include trees and other plants.

touched on previously, but the third week of the project, split between weather data and biodiversity, was the week in which Hamish was the most vocally disconnected from the project. The afternoon session, reading up on biodiversity, has already been touched on to some extent; after skimming the provided pamphlet and performing a cursory internet search for additional resources, Hamish and his group turned to unrelated websites more tailored to their non-academic interests. It was the morning session that provided the most insight into Hamish's preferences (18.03.23 lns 5-8):

> Hs:…you've got to find the right mark when teaching of giving students enough guidance but not giving them too much cause if you give them too much then you're just doing the work for them if you don't give them enough then they're not going to find it at all

Hamish felt that in this case, the final objective was clear enough (compare weather data to weather along the creek), but that the criteria were vague enough that he could not be sure he was on the right track with what they were doing. Hamish had read scientific journals before, but generally ones provided for him; searching for publicly available data that matched what the school was collecting was not something he had been prepared for, and his frustration was evident. In a voiced sentiment echoed by his group, Hamish felt as if they needed to either have more guidance with a set objective, or be left to determine their own objective from the resources provided. While there were several moments Hamish felt uninterested by the project, this was the only time he displayed an active dislike, stemming most directly because "we understood what we were meant to do we just couldn't get there cause we didn't have the right resources or we couldn't find them" (18.03.23 lns 14-15). This statement suggests that Hamish felt the frustration of low self-efficacy (Bandura, 1977) and became disengaged when he perceived that he was not able to successfully complete his task.

The importance of being in control of his learning, of having or setting achievable goals, reappeared as Hamish prepared and then participated in the Primary day. As Hamish and his group went about planning their flow deflector project in particular, Hamish advocated (primary) student agency to his group, favouring a strategy of giving the students the goal of clearing the water quickly, and the resources to do it. He also pushed for an element of competition, and the

chance for students to have multiple tries to improve upon their ideas. Particularly telling is the fact that Hamish stuck to these ideals as the Primary day came to pass, resisting the urge several times to make corrections to the younger students' work, and instead prompting them to self-reflection by asking them if they thought the design could be improved, and how. He made a point, as was noted in the observations as well as by Hamish himself in the post-interviews, to at most guide them towards the answer by asking them questions and stirring discontent with their initial ideas (Champagne et al., 1985b) in order to help them develop their strategies.

One of Hamish's most frequent complaints had indeed been that he knew there was a set objective, but was not quite sure what it was (18.06.11 lns 400-403):

> Hs:…I would have definitely preferred it if at the very start we were sat down we were sat down we were given an introduction to it all that's good I would have preferred it if the syllabus or the the general sort of 'this is what's going to happen, this is what's going to happen' was shown to us so we got an idea for it…

It was this introduction that Hamish tried to mimic in the Primary day, by offering each group a short introduction to flow deflectors, a short bit about the materials they had, and the criteria against which their performance would be judged. He also tried to keep everything short and to the point; another complaint of his, both at the time and in reflection, was that having all the lectures condensed at the beginning meant that "we got to like a few weeks down the line and we were dealing with activities in which we needed to know this information but it had been so long we'd forgotten" (18.06.11). Hamish did attempt to correct this in his own teaching by being concise at the start and allowing the primary students time to take what he had taught them and apply it (Figure 5) before adding to their instruction. He felt this was a strategy he wished he could see more in his own lessons "that's the best way of remembering things you're learning the information, you're applying it, by applying it you're helping to remember it", marking another moment where his personal learning preferences helped inform his strategy to engage and enthuse the primary students.

Figure 4.2 Two examples of flow deflectors designed by Primary students under Hamish's guidance (18.05.16)

In general, Hamish proved a fascinating participant, due in no small part to his willingness to make explicit his ideas and opinions relating to both the content and structure of the Challenge project. His unexpected take on the main point of the project also provided some highly valuable insight on how students in such projects do construct their knowledge structures as they work to meet their objectives. Whether this divergence is due to the nature of the project, his prior knowledge (even if he was not explicitly aware of its existence), or to his frequent absences and the second-hand nature of much of his direct instruction, I cannot say with certainty. However, there are several compelling ties between the activities Hamish engaged in and his learning across various domains, including content knowledge, self-directed learning, and developing new feelings/interests. How his case compares with those of his contemporaries will be considered in Chapter 7, and the larger implications of all three cases will be explored in Chapter 8.

CHAPTER 5- Hannah and the computer science project

5.1. Introduction

The following two chapters follow the cases of two young women participating in the Computer Science (CS) Challenge Project, another of the options provided to the Year 12 students in the Spring of 2018. This chapter will start by outlining to project itself, and then present the case of Hannah, the first of the two participants to complete this project. Her narrative will focus primarily on changes to her thinking as it relates to programming logic and syntax, and on Hannah's growing abilities as a self-directed learner. Because Hannah had prior experience with coding in general and with the project language in particular, the focus was not primarily on the number of functions she knew (though certainly this number increased during the project) but rather her ability to self-direct and learn independently. However, she did also develop several new ways of thinking not just about the code but about coding within such a project, and so this will be explored in this chapter as well.

The second chapter will focus primarily on Jane, one of Hannah's teammates whose role required the development of very different skill sets. These skills will be outlined as part of the report on her case, and then a comparison of the two cases will conclude her chapter. Because Hannah and Jane were in a group together and often provided opinions on the other, there will be some overlap within the cases as well; this will be noted where relevant. For this reason, quotations from each participant will be annotated with the first initial of their chosen pseudonym (ex. Hh.18.04.24) when the perspectives of both are presented within the same section. A glossary of technical terms can be found in Appendix E, and as part of the text where a discussion of accepted use is necessary for understanding of the participant's thought process. Terms included in this glossary are denoted with a * in the first instance of the term.

5.2. The computer science project

The Computer Science (CS) project at Cambridge Academy for Science and Technology (CAST) differed from the water management project (WMP) in a number of key areas. First, the project was designed and run in collaboration with not one but two local employers: Arm and Cambridge Intelligence. The project was also part of the Engineering Education Scheme (EES),

developed by the Engineering Development Trust (EDT) to help address the shortage of qualified engineers in the UK. Successful completion of the project also qualified each student for a Gold Award as part of the Industrial Cadets scheme. What role each of these organisations played in the project will be laid out in greater detail below, and in the cases themselves where the organisations played a direct role in the participants' experiences.

The project itself made use of a JavaScript software development kit (SDK) developed by Cambridge Intelligence. This SDK, called KeyLines, was provided to the students free of charge for the duration of the project, and allowed students to take raw data and create a visual representation (see Appendix B.5 for examples) that could be more easily interpreted. This represented the programming skills portion of the project; the project brief (Appendix A.6) presents these skills as a means to an end. Students were asked to then analyse the visualised data and to prepare a product designed to help them either sell the intelligence found within their network of data, or to identify a problem within the data and sell the solution to that problem. This required skills in data analysis and marketing, among others. While members of the Cambridge Intelligence team did come in for several sessions, in more often were mentors from Arm, another Cambridge-based company who were providing sponsorship for this project.

The Arm mentors came in each week after groups were formed to help students with the more organisational aspects of the project, such as setting a timeline for themselves, dividing tasks, and deciding how best to design and market their product. As they were not familiar with the SDK being used, they were not able to provide advice on the coding aspects of the project. This division meant that students were able to receive help in certain areas at certain times, and therefore had to account for this in their planning. As the groups moved through the project, the mentors often challenged them with questions relating to their strategy, as well as providing formal feedback on the students' reports, which were written as the project progressed. These mentors then helped students prepare for the presentations, given as part of the Celebration and Assessment Day (CAD) and the conclusion of the project.

The CAD had two main purposes: to provide students an opportunity to launch their product and sell either the intelligence or the solution (as outlined in the project brief), and to present them all with their Industrial Cadets award. This award was given to all participants who completed the project, and represents a qualification that each student is able to put on their CV's as they pursue apprenticeships, careers, or university places in the next year. The Industrial

Cadets award is relatively flexible in nature, with a minimum 50 hours of participation, with a suggested breakdown of those hours provided to participants. The EES-Applied scheme provided the framework through which these requirements were met, and provided specific role descriptions (Appendix A.7) for all the stakeholders in the project, as well as a timeline for certain benchmarks. For the purposes of presenting these cases, the two parties most directly involved are the mentors from Arm (frequently referred to by the participants as 'the mentors') and the developers from Cambridge Intelligence (often referred to as the 'Cambridge Intelligence people').

Because the project did have to meet certain external criteria, and because students were given a particular data set (Amazon product reviews and limited user data) and SDK to work from, there was a clearly defined outcome to this project. Students were supposed to transform the data into a more visual format, then interpret the data in such a way as to sell intelligence to a third party, or to develop a solution to problem that was identified by the students from the data. However, both of these options could be considered quite open-ended. There was no specification given regarding the quantity of the data to be used, the layout of the visual, or the type of intelligence to be sold or problem to be solved. As such, each group had a fair amount of flexibility in the design and management of their project, which in the cases of Hannah and Jane meant a great deal of adaptation in the early weeks, and improvisation as the project went on. Their cases will examine these adaptations in greater detail, along with the skills developed as the project progressed.

5.3. Challenges to Observation

Like the Water Management Project, there were specific challenges faced in observing the CS project. The first of these is that it did run parallel to the WMP, and so it was not possible to observe either project in its entirety. For the CS project, this meant missing segments of time in which the participants were attempting to code certain sections of the project, particularly on mornings when I was out with the WMP during their field research. Certain elements of the CS project helped to reduce the impact this had on the study, however. Hannah and Jane's group was extremely organised, using an online task board to plan out and allocate specific tasks, so it was possible to know ahead of time who was completing what task, and then to see notes after

task completion. All coding was done individually, but was then fed into a master copy on a Git* website, to which I was granted access. In order to protect student identities and the proprietary rights of the developers, no screenshots of this code were taken, though notes were made and referred to in our interviews.

Of particular benefit is the fact that, by accident rather than design, both Hannah and Jane ended up in the same project group. This had not initially been so, but after a restructuring in Week Two of the project (Table 5.1) the two participants were put together in a group with a third member, Matthew[31]; an additional member, Chris, joined them the following week. This was advantageous for several reasons. The first is that I was able to work from a single vantage point when observing the CS project, as Hannah and Jane were working side by side. The second is that, while in the interest of anonymity I never disclosed to them the other's participation in the study, they often referred to one another, thus providing confirmation (or in some cases interesting contradiction) of certain events. Another benefit of the CS project was the structure itself; while the WMP dedicated each session to a particular aspect of the project, the CS project was designed to allow students to set their own objectives each week, and these objectives often built upon one another. That is to say, if a certain task was being undertaken, it was logical to assume that certain other steps had taken place to make it possible. This made it quite easy to catch up on anything I missed, and to ask about the progress in those particular areas in the next interview. For more on the interview schedule and its justification, please see the methodology.

Table 5.1 Schedule of Challenge Days (C), and interviews with Hannah (H) and Jane (J). All dates refer to the 2017-2018 academic year

	02.26	03.05	03.12	03.19	03.26	04.02	04.09	04.16	04.23	04.30	05.07	05.1.4	05.21	06.04
Monday			J		J			J		J				
Tuesday				H, J	H			H	H	H		H		
Wednesday		C	C	C	C			C	C	C	C	C	C	
Thursday	H, J			H	H, J				H			H	H	
Friday		H, J	H, J	J				J	J		J	J		J

[31] All names present in this report are pseudonyms, to protect the identity of the students

5.4. Hannah's background

Hannah is one of two student participants who completed the Computer Science (CS) project at Cambridge Academy for Science and Technology (CAST), and of the three total participants, the only one to have actively chosen the project she was undertaking. Hannah was at the time of the project 16 years old, and completing her Year 12 studies enrolled in A Level Computer Science, Maths, and Physics. With the aim to eventually work "somewhere in NASA" (18.03.01 lns 104-105), Hannah had joined CAST only a few months prior after finding the school name during her UCAS process and being intrigued by the concept. While she readily admits to choosing a school in Cambridge mainly for the name, Hannah was also quite pleased with the small class sizes and specialist attention she received at CAST. She credits this and the related nature of her courses for her ability to improve in her performance as the year went on (18.03.01 lns 93-96):

> Hh[32]: …they use maths in Physics so obviously that was part of the revision umm in Computer Science we do this thing called Boolean Algebra which is basically algebra the same sort of thinking and because all three subjects use that same sort of logical processing I managed to really improve my grade so I was really happy I very much enjoy Maths

Hannah revealed in her reflection of her first cycle of mock exams that she believes each of her subjects require the same sort of logical thinking as one another, and as we went on, she on several other instances explicitly commented on how important she felt this logic to be. In evaluating her teammates, for example, Hannah's belief in the strength of their 'programming logic' featured heavily in her discussion (18.03.20 lns 41-44):

> Hh:…Matthew can program as well he can get a grasp of it much quicker than Jane um so he'll probably end up helping me out and then once Jane kind of understands the logic cause she does maths as well so she'll find the logic of programming quite easy um it's just knowing the syntax which she can then just ask me for…

[32] Hh is used whenever Hannah is being quoted

This same discussion, held shortly after the formation of project teams, revealed a great deal about Hannah and her beliefs about her role within project. There was very little doubt in her mind that she would be the lead programmer in her group. This is perhaps unsurprising, as not only did Hannah have the A Level Computer Science background, she had actually completed a week of Work Experience with the very company that had designed the software development kit (SDK) they were given to work with during the project. Hannah believed her abilities and her insider knowledge made her the perfect candidate, though she planned to share some of her tasks with her teammates (18.03.16 lns 80-85):

> Hh:…obviously I did work experience here so I kind of have a bit of advantage to everybody else I know what the actual software is, I have a little bit more JavaScript knowledge than everyone else so basically when they were explaining the task I knew straight away what I had to do but obviously I have to explain that to those two as well um so they understand cause I can't just go away do it and then to sit there and just expect them to understand what I'm doing we have to work as a team to get it all done…

Hannah's self-image as a programming expert was reinforced by her interactions with both her peers and her instructors. Particularly in the early weeks of the project, Hannah was approached by students from other groups for advice on how to navigate the KeyLines SDK. In the beginning, it was common enough to see her responding to these enquiries with enthusiasm, but once she had decided to focus on the competition aspect of the project, Hannah did decide to keep some things to herself (18.03.27 lns 84-88):

> Hh:…we chose the GitBucket [sic] one cause you can make a private repository for free um yeah cause I think Michael was gonna use just normal Git but Matthew said don't cause you'll get in a lot of trouble and Michael doesn't know any other ones so we kind of stopped him from using our same methods so he's just going to be slow…

Incidence of Hannah's providing assistance to other groups also generally decreased as she started to face more difficulties herself. This was in part due to her increasing focus on winning

the competition, but also due to lack of confidence in her own work. This will be examined in more detail later in this chapter.

5.5. Hannah's early views on the project

Unlike most if not all of her peers, Hannah came to the Computer Science (CS) project with a fairly well-developed understanding of what tools would be available to her, given her relative familiarity with the KeyLines software development kit (18.03.01 lns 21-27):

> Hh: They gave us a brief overview of it all so I did work experience with Cambridge Intelligence and they're helping out with this project so we're basically helping them with their software, they're giving us their SDK and we're just looking at that developing JavaScript skills and basically just a programming sort of thing and then I I think I vaguely remember it was yesterday afternoon then we are going off to do some sort of engineering thing and we're uh working with the um Industrial Cadets Gold Award thing as well. Basically all I remember but it's a really interesting, something I enjoy doing.

Almost as soon as Hannah was asked about the project and what it entails, she volunteered that she had prior experience with the company and their product. She had attended a work experience[33] placement at Cambridge Intelligence earlier in the year, and it was one of the first times where Hannah had been offered any formal training in Computer Science, having until this year been primarily self-taught (18.03.01 lns 118-130):

> Hh: Well I did it for work experience uh I have done programming in the past umm in my spare time when I was at secondary school umm I didn't have the opportunity to do Computer Science um cause we didn't have the teachers available for it so I kind of ish taught myself the course but only the programming side of it all and I kind of made the beginning to a game
>
> R: Okay

[33] In the United Kingdom, it is typical for sixth form students to complete a placement of approximately one week with an employer in a field that interests them. Hannah's had been earlier in the year at Cambridge Intelligence, the company that produces the KeyLines software

> Hh: But I used that for cause I did Duke of Edinburgh Bronze and this thing called Arts Award so I developed that game to use for those awards and that's kind of where I realised I really liked programming. I developed my skills there um but with JavaScript, I first started using that whenever we did work experience this year (last year maybe?) I think but yeah basically I went to there and I knew I had to do programming but I didn't know what language it was in so in the interview he said JavaScript so I had to a week before work experience kind of put some side time aside and try to teach myself some JavaScript but now with the new Challenge I'll have a chance to develop it further which will be good

Hannah and I were in general agreement that this work experience, and her ability to self-teach, would hold her in good stead for this Challenge. Where previously she had been able to teach herself only what interested her, this project would require Hannah to develop skills based on what was necessary to complete the project. Hannah accepted that this would be less open-ended than her independent work, but as seen above viewed the project as an opportunity to further develop her skills in this new programming language.

Hannah's self-efficacy (Bandura, 1977) at this early stage in the project is quite positive, based not only on her previous experience but on the feedback she has received from others, most notably her Computer Science instructor (18.03.01 lns 133-144, emphasis added):

> Hh: Umm well it depends because some people only know two languages the ones we've learnt in class which is Visual Basic and C# um whereas now I know 4, I know Python, Visual Basic, C#, and a bit of JavaScript so I feel like if you didn't do Computer Science in secondary school obviously I didn't so I had a disadvantage when I first joined however because of work experience and things I've done outside of school I now have more of an advantage because I know more languages than everybody else so that's been quite useful **now in the Challenge [Instructor] wants me to help people try to work their JavaScript**
>
> R: That's great! Do you think that's something you're going to enjoy doing? Like do you enjoy taking on that almost tutorial role or

> Hh: Yeah I kind of like taking the leadership role telling people what to do umm but no yeah I'm really … I'm not that great at clearly telling people what to do but I do like telling them so hopefully they'll understand yeah

Lin (2016) found that social persuasion, which includes communication, feedback, encouragement, and others' expectations, is a main predictor of students' programming self-efficacy, and so it is likely that the positive feedback Hannah received from her instructor impacted her beliefs regarding her programming competence. At this point in time, Hannah had not been offered the project brief and so was unaware of the specifics of the task ahead. She felt, however, that having been called upon by her instructor to act as an expert in the programming language of the project, she would be able to take on a leadership role in the weeks ahead. It is also clear that she relished the thought of being the expert, and in particular the thought of being able to set tasks for her peers.

Hannah doesn't just place importance on programming for the sake of producing workable code; she also believes that the logic necessary for coding is important in daily life as well (18.03.09 lns 83-89):

> R: So you'd advocate students growing up from here out learning to code um learning to program?
>
> Hh: Yeah even if you don't do anything like even if you don't do Physics and Maths or Chemistry or whatever you do English and History programming teaches you to think in that way that can be useful for everyday life solving problems so I think even if you just learn Python literally the most basic programming language it's you can learn it in a week to be fair um and then you start thinking in a different way and it can really help people

The premium that Hannah places on the sort of logic that develops from programming indicates that she views this project not only as a way to develop her JavaScript proficiency or to gain a recognisable qualification but as a vehicle to help shift the ways she and her peers think. Other exchanges make clear that she believes this thinking is transferrable to other areas as well. Interestingly, it is quite clear that Hannah believes this useful logic *of* programming is not limited

to logic *from* programming, as is made clear when groups are formed and Hannah is evaluating her team members (18.03.20 lns 41-45):

> Hh:…Matthew can program as well he can get a grasp of it much quicker than Jane um so he'll probably end up helping me out and then once Jane kind of understands the logic cause she does maths as well so she'll find the logic of programming quite easy um it's just knowing the syntax which she can then just ask me for so we'll probably all end up doing bits and bobs but mainly something like that.

Here, Hannah reasserts herself as a group leader, referring to Matthew's contribution as "helping her out". She also suggests he will "get a grasp of" KeyLines much more quickly than their third team member (and, [unbeknown to Hannah,] fellow research participant) Jane. However, Hannah believed that because Jane does A Level Maths, she would be able to understand the logic of programming quite quickly. This suggests that she does not view this logic as something innate, or exclusive to Computer Science. It also suggests that, in the earliest stages of the project, Hannah believed that eventually all members of her team would contribute to the coding as well as other associated tasks.

5.6. Hannah as a self-directed learner

5.6.1. Early evidence

After the team is given the project brief (Appendix A.6), Hannah and her team began to consider the organisational aspects of the project. Students were introduced to (or in some cases reminded of) SMART objectives: specific, measurable, achievable, relevant, time limited, and then offered the opportunity to collaborate on a hands-on mini-project. This mini-project, to build a roller coaster out of paper, was the first major indicator of Hannah's competitive side. Her group was the only one to successfully build in a loop on their coaster, and this was due in large part to her push to take risks with their design. By the afternoon, groups had shifted, but her goal remained the same; Hannah was determined to take the lead and use her expertise to

create a top-quality product. She was supported in this determination by an online personality test[34] she and her classmates had been asked to take (18.03.16 lns 30-35):

> Hh:… mine came out to be like I think it was called executive or something and the description was 'likes things to be well ordered quite bossy likes to be the leader' and I was like yeah and then [Instructor] came over and he was like 'yeah basically expected that' and I was like 'yeah little bit' and so no I wasn't surprised by it in fact it kind of made me realise who I am a bit more and kind of where my role was in a team which is the best role the leader

Hannah knew early on that she was suited by experience and personality type to be a driving force within her group. However, she was quick to consider the teamwork aspect of the project, and to consider what exactly lay before her as leader of her team (18.03.16 lns 20-24):

> Hh: …I think using the skills for the project management little task will be really useful for this cause we need to work together to plan um what we're going to do be able to execute it and actually do it kind of thing seeing the fact that um Jane also doesn't do coding has never done it before so me and Matthew are also going to have to kind of support her through it…

The group had only a few short minutes after forming a team to introduce themselves and start to consider their roles. Despite her belief that she would be the team leader, Hannah from the start expressed a desire to plan and work collaboratively. It was established in section 5.5 that Hannah believes her teammate Jane would be able to easily pick up coding thanks to her work in subjects with similar logical structures. However, this does not mean Jane would not need help; Hannah saw it as the responsibility of herself and Matthew (a third group member) to support Jane as she works to develop some elementary programming skills.

[34] The test, found on https://www.16personalities.com/free-personality-test, was provided by the instructor for the express purpose of sorting the students into complementary groupings

5.6.2. Hannah's developing self-direction

Week three of the project brought a change to the group, with the addition of a fourth group member who has extensive programming experience, much to Hannah's delight (18.03.22 lns 22-31):

> R: Okay um and then uh you added a new team member to your group uh you seemed fairly enthusiastic about that, volunteering pretty quickly
>
> Hh: Ah yeah
>
> R: How has that changed the roles within the group?
>
> Hh: Not much he is also quite a good programmer he's in our Computer Science class … he's actually brought forward some pretty good ideas for the options panel and um things like that and he's helped me with the CSS coding cause he understands it well so it's actually been quite efficient bringing him to the team so I knew he was a good programmer so I was like 'yes please' [laughs] so yeah it's actually made it a lot easier for us

The addition of this new member, Chris, meant that the responsibility for coding was spread out amongst a greater number of people, and with this in mind the team set for themselves a timeline of tasks. In the earliest iteration of a project timeline, the group created a board featuring several rows relating to the different types of tasks, either programming or design. Tasks were written on self-adhesive note cards and could be claimed by an individual and then moved from left to right in columns such as "to-do", "doing", and "done"[35]. Mentors from Arm came in to offer the groups advice on how to structure their boards, including a suggestion to split tasks into small sub-tasks to make them more manageable.

Hannah and the team took this advice quite seriously, working together to decide how best to approach the vast amount of data they had before them, and the multitude of tasks necessary to present it in a readable form (18.03.22 lns 45-55):

[35] Because the design of this table included identifying information such as student names, no images were taken.

Hh: Uh we're gonna kind of work with what we've got currently um and then try and then once we understand KeyLines more bring in more data and start you know obviously cause then we'll have different categories and so it will will be much more wider um because obviously once we have the brands some of the brands might make the same sort of products but some of them might not make anything similar so they'll just be on their own over there so if we could find more brands that make that sort of products then we can somehow link them and if there's a brand that makes those products AND those products then we can make one big connected network which will look a lot nicer as well than having loads of nodes on their own off in the distance

R: Yeah

Hh: So we're going to try to minimise what we've got and then start look into adding more

In the early stages of product development, the team decides on a deliberate strategy of starting to experiment with the software using small amounts of data from the electronics category[36] before adding in additional categories of data to the finished code to create a final product. This moment also provides some insight into Hannah's concerns about the data they have selected; there is a very real chance that some product nodes may not connect to any others based on the information available. By setting a working plan involving a small amount of trial data and a provision to add more as needed, Hannah and her team seem prepared for multiple contingencies.

The following week saw coding begin in earnest, with Hannah and Chris working to understand the source code for what they hope will become their signature feature, 'combos' which essentially combine multiple nodes into one based on a shared characteristic, such as brand. Hannah was particularly keen to get combos working because she had insider knowledge that combos are a new feature for the company, and so mastering them will be an impressive feat. It is as she prepared for this task that she met her first real check (18.03.29 lns 8-14):

[36] Students were provided Amazon review data from the majority of product categories. The team determined for themselves the category from which they would take data

> Hh:…I've been familiarising myself me and Chris with the actual coding for making combos and stuff like that uh which we were both kind of struggling with last week because when I did work experience there they didn't give me data to work with I had to make my own so obviously I wasn't going to make 4,000 lines worth of data I was only going to do about like 20 so I was only working with a small amount of data so when I was coding them to do things I would just hard code it or instead of finding common links I just wrote all the separate nodes I wanted within a combo

Hannah had come to the project fairly confident that her work experience would give her an advantage, and in many ways it likely had to this point; it did mean she knew what features are possible and what might most appeal to the expert panel of judges later. She could not directly translate her skills from work experience here however, as the nature of the data was quite different. She knew *what* to do; she needed to "…write um a line of code that will reference to all of the bits of data that have something similar within them and then pull it out instead of writing each separate one like I did" (18.03.29 lns 16-18), but on this first attempt she was unable to find a solution. It is a clear blow to her self-confidence, as she made quite clear that while she had an experiential advantage, it was not enough in this case to help her to work through her current problems (18.03.29 lns 137-140):

> Hh:… everyone apart from me hasn't even used the software before and I'm struggling and I've used it and I think there's only one guy who's managed to get combos going – ish um but he's really really intelligent with programming so the rest of us are just kind of like mediocre we really need help

Hannah still clearly believed that she *should* have had an advantage on this project, due to her experience. However, she here described her programming ability as 'mediocre', which is quite at odds with her earlier optimism. Her frustration was perhaps compounded by a concern that the resources available to help her were insufficient, particularly in terms of personnel (18.03.29 lns 127-132):

> Hh: Yeah I don't understand the point of these mentors because they're not actually from KeyLines … most of us aren't having troubles with the actual design we're having troubles with the actual code so what we'll talk to them and they won't know kind of

> they'll try to help but they don't actually know they'll ask questions about how's our planning going how's the report going blah blah blah but they won't actually know like if cause some of us some of us are genuinely having problems with the KeyLines code and they don't know that

As Hannah lost faith in her ability to complete the work independently, the freedom and lack of explicit guidance she had been receiving began to feel more like a burden than a benefit. Hannah valued the design team, as well as the need for organisation and long-term vision, but she was feeling unsupported in terms of experts upon whom she can rely. This suggests that Hannah's feelings of mediocrity mentioned above were impacting her confidence in her ability to work independently as well. She did not minimise the contributions of the mentors to overall group productivity, stating that "…they've helped out with kind of minimising tasks how to split it out which has helped um especially with my board and the time plans and stuff…" (18.03.29 lns 162-164) but, as the lead programmer, Hannah was more concerned about her share of the project.

The pause resultant from the half-term holiday provided some opportunity for a perspective shift, and when she returned from the break, Hannah had a renewed sense of purpose (18.04.17 lns 5-9):

> Hh: …I was just kind of organising the Trello board [Appendix B.6] a little bit more and trying to find what problems that we have that we can work on so I've identified what we need to do, I just don't think anyone's done it uh which is good cause we didn't really know where to start a few weeks ago so now we know 'okay we need to do this, we need to do that' so basically all I've done is just set us out some goals and who's gonna do what

While Hannah had not yet found any solutions to the problems she had been dealing with, she then at least had a sense of what needed doing, and who was the best person to do it. Hannah still had not had any interaction with the experts she felt would be able to guide her in her project, but she was spending time with what resources she did have access to (18.04.17 lns 38-45, emphasis added):

> Hh: Uh well me and Chris have just basically been looking on the KeyLines site and just trying to see how they call from the data file because the files are separate when I did mine I had it all in one file because it was barely any data I could just have it in there um but **we have to call* to the other file and drag out the pieces of data that have this one thing in common and we don't know the syntax for it, we know the logic perfectly well, we know what we want to do it's just we don't know how to write it** so the way we find that out is just go onto the KeyLines on their API references and we we've just got to read through it all, it's just a lot of reading, finding what we need…

Hannah's previous experiences with the company had not prepared her for all the specifics of the task at hand; where previously all of her data was easily identifiable (as she wrote them herself), here she had to find a way to call the data she needed. She and Chris planned to dedicate time the following Challenge to working through the API references, demos[37], etc.

5.6.3. Seeking help where needed

The day after the above interview, Hannah and Chris reached a point in the coding where they can no longer rely solely on the references or the demos, and so Hannah made the decision to email the company directly to ask for assistance in understanding how to call the data they need. She was the first student to do so, as the majority of other groups were at this point either still experimenting with trial and error, or moving on to other tasks for which they had the requisite understanding. Her issue required several emails to be exchanged with the Cambridge Intelligence team, but she eventually felt confident enough in their information to return to programming. Her work was then frequently punctuated by requests for assistance from other groups; her returning confidence appeared to have indicated to the others that she had found a solution to the problem, which had been an issue for much of the class.

[37] Demos in the case of this project refer to samples of KeyLines features such as combos or creating links, alongside the source code to create that feature. Due to the proprietary nature of the software, no screenshots are included for publication within this work

Speaking to Hannah about that particular exchange, it was clear that while she did then have a better understanding of the issue and what needed to happen for it to be solved, she was not much closer to figuring out how best to accomplish it (18.04.24 lns 6-25, emphasis added):

> Hh: Uhhh well we were trying to combine nodes and we knew the syntax for the code **we just didn't know how to reference* to the data umm because what had happened was when we had taken and downloaded the data from the site that they provided us with** umm they then gave us this thing called like parse parser script or whatever which um would change that data format to a more KeyLines friendly way cause KeyLines couldn't read that formatted way to be able to interpret it and visualise it but we can't see the output of that we only see basically the raw data after we've downloaded it which is a problem cause then we don't know what the individual ids are for all of the nodes…
>
> R: Okay
>
> Hh: And so we got really confused about that so we emailed him he was kind of clear on some things umm but it apparently just wasn't as easy as that you had to iterate through every single node and yeah it got it got really complicated so um we're hoping that they're coming either this week or next week to clear things up for everybody cause … we're all at this standstill point where we're not making any progress because we can't get the data we've got so much ideas and we know how to do them we just can't get the data to go into it so nothing nothing has progressed for the last two weeks unfortunately

Hannah's decision to reach out is indicative of her abilities to effectively assess her abilities and resources to determine what she needs to succeed, which in this instance meant being the first to email Cambridge Intelligence. The emailing did not lead to a definitive solution to the problem, but several important developments did result. First, Hannah was able to better articulate the source of the problem, which appears to be the way in which the parser* restructures the data. Because the group was unaware of the ids associated with the individual data points, they could ask their code to call that data. They had not quite been able to solve this issue through email, but the emails have at least given them a plan of action moving forward.

To the general relief of most if not all of the class, the following week did bring in three members of the Cambridge Intelligence team. Because of the demand, Hannah and her team had to wait approximately 45 minutes before help was available, and in that time Hannah continued to try small adjustments to solve the problem herself, with no results. When an expert did join them, Hannah was able to take some of the conversation from the emails to describe the problem in sufficient detail that the fix occurs in a matter of minutes. I asked Hannah the following day about the specifics of the issue (18.04.26 lns 21-37):

> Hh: Yeah so we had uhhh for the iteration process an 'if' statement and it had two arguments within that 'if' statement and all she did was split it into two separate statements and that was it
>
> R: Okay
>
> Hh: … it was literally something so easy which was annoying cause we probably after another week probably we could have done it but don't have the time really to be messing around with it so it was good that she managed to come in and do it
>
> R: Yeah. Had you ever come up with a problem like that before where you had to separate out statements like that?
>
> Hh: Oh yeah all the time people always go [inaudible] on problems umm cause usually you can have two arguments with an 'if' statement but if they're kind of like sensitive like like it's really difficult it's kind of a 50/50 chance whether you've got to separate it or keep it together so it's kind of like we didn't really think that that would be a problem

If Hannah had previously been aware that splitting an 'if' statement was so often the solution, it is quite surprising that she had not attempted this in her own work. The more likely explanation is that she came to this conclusion after her interactions with the KeyLines expert. It is also possible she was aware of this possible solution, but was unsure how to execute it successfully on her own. In the early stages of the project, she worked primarily from her previous experience and the examples she could find in the demos rather than taking any significant risks with her code. If she had been aware of this possible solution, she may well have felt splitting the statement to be an unacceptable risk at the time. After this first problem was overcome, Hannah expressed more of a willingness to engage in some trial and error with her coding,

particularly after a second expert comes to discuss another issue and suggests such an approach (see 'wish-list' quote below).

This visit by Cambridge Intelligence represents a shift in the project; before, the work was focussed primarily on troubleshooting, with peripheral attention to concept and design. With the node id issue sorted, a new issue emerged. The data itself was not providing any obvious links, so while the products were then in brand combos, the combos themselves were in isolation from one another. Because one of the team's aims was being able to use links between the combos as part of 'selling the intelligence', creating these links became a major priority (Figure 5.1), as do some smaller cosmetic tasks such as colour coding reviews and team branding.

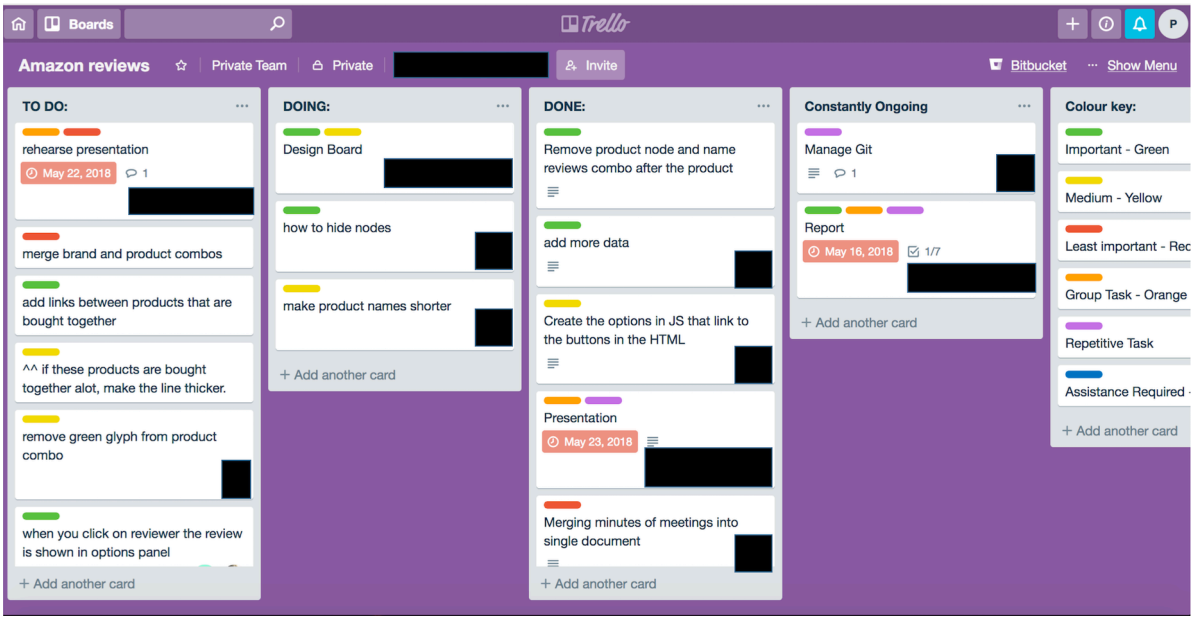

Figure 5.1. Screenshot of final Trello board taken just prior to the final presentation week

As such, the to-do list on Trello became significantly longer, and for the first time Jane is asked to work in a programming capacity, focussed on colour coding the nodes according to their rank (one star red, five stars green, etc.). Hannah is also preparing to take on some of her more 'wish-list' items concerning the presentation of the nodes (18.05.01 lns 48-52):

> Hh: Uh so mine is to kind of I want I know we've got the combos done but I just kind of want to see whether I can have open combos maybe with brands and stuff so

maybe just try to finalise the combos so it's kind of they're more together than spread out so that's kind of what I'm going to focus on tomorrow which shouldn't be hard now I know how to do combos I should hopefully get that done within a period which will be nice

Hannah's next task for herself was a relatively ambitious one; having been given the necessary information to create combos of product nodes, Hannah planned to expand upon the combos, adding in features that she felt add to the aesthetic of the brand. She then had the code in place for standard, closed combos (Figure 5.2) but believes that a default open combo (Figure 5.3) would better suit the client, and so had set this goal for herself.

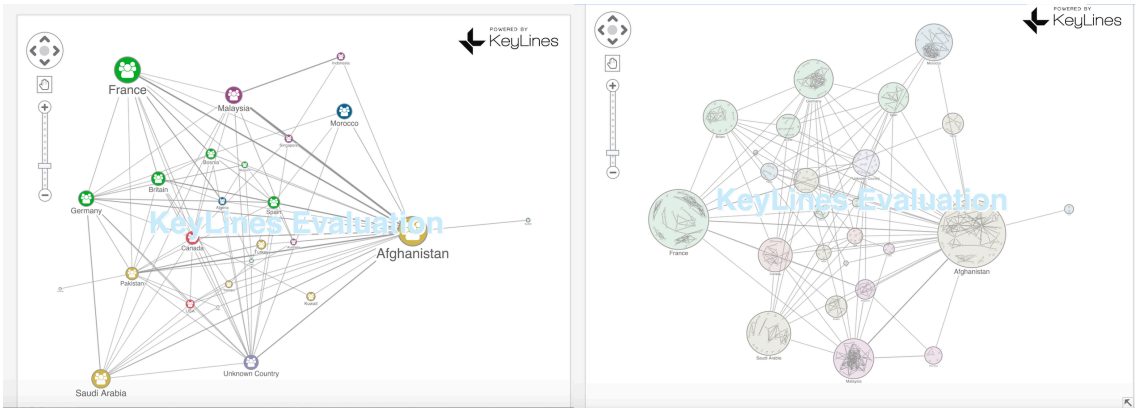

Figure 5.2 (left) and 5.3 (right). Screenshots from the KeyLines website showing closed and open combos, respectively. Images used in interviews of 18.05.01. Reproduced with permission

Hannah's time is split the following Challenge session, as she has taken over the editing of the report so that Jane can have some time for coding. Jane faltered early on in the task (from observations on 18.05.02), but because Hannah is engaged not only in editing but in working on the default open combos, she relies on Chris to provide guidance to Jane. When Jane determines she is unable to finish her programming task, Hannah quite happily turns control of the report and presentation back over to Jane, and returns to coding. A look at the final Trello board (Figure 5.1) reveals that as the project comes to a close, each member of the team[38] has returned to their perceived areas of strength as the project came to a close.

[38] Names and user icons redacted but the items in the 'to-do' and 'doing' tabs reflect Hannah and Chris in programming tasks, with design tasks assigned either to the whole group or to Jane and Thomas (who was also in charge of managing the Git)

5.6.4. Final thoughts on Hannah as a self-directed learner

Hannah and her team had a very situational perspective of their abilities and thus the roles that needed filling; when Hannah's self-confidence was high, she was quite ready and willing to take charge of the group and to take risks with her work. She and her coding partner Chris established for themselves early on a protocol of reviewing the source code on relevant examples, as well as the API reference, rather than seeking support from either their instructor or the industry experts. The instructor in charge found this ideal "you know that project learning is working because I don't have anything to do". As problems began to emerge with the code, Hannah became more reliant on outside help, but continued to set optimistic targets for herself and the group. Even her decision to email the experts demonstrates her ability to access the necessary resources to meet her own success criteria. The resolution of her difficulties led to a rapid expansion of these criteria, and when asked just prior to the final presentation, Hannah seemed to feel that her approach was one of merit (18.05.17 lns 154-162):

> Hh: Yeah we've had quite a bit of umm like I don't know what the word is like moments where we just haven't been able to progress any further and so you know me and Chris are um resilient we don't want to back down we want to really tackle it and that's kind of been a problem because we will keep trying to tackle something that sometimes we just will not know we will not know unless we ask the KeyLines people and then we have to wait for them to answer…but it does pay off when we finally get manage to do it so yeah

It would have been impossible to discuss Hannah's journey as a self-directing learner without discussing superficially her skills development as a programmer as well. However, while I will show in the next section that her application of programming skills and knowledge follow a roughly linear trajectory, here her tendencies as a self-directed learner were more of a gradual oscillation[39]. This is not to say that the two were unrelated; her initiative and self-regulation appeared to be quite tied to her *perception* of her application of programming skills and

[39] It would be natural to wonder if Hannah's self-directed learning behaviours here met the threshold of *semi-permanent* in terms of behaviour change laid out in the literature review; this will be discussed in greater detail in s§ 5.8

knowledge. The narrative here of her development as a self-directed learner is quite closely tied with the narrative of her development as a programmer, and thus this next section is intended to provide some insight on the phenomena presented in this one.

5.7. Hannah's thinking about programming

Because the preceding section focussed on *how* Hannah learned, there was by necessity some attention given to *what* Hannah learned during this project, although not in considerable detail. The purpose of this next section is to consider in a more in-depth manner the ways in which Hannah developed and applied her knowledge of the nature and process of coding in terms of the product outcome, rather than her personal learning. While much of her story here overlaps with the previous section, the purpose here is to add detail focussed on different aspects of her learning, and thus complete the story begun previously. Structurally, this section is subdivided to explore first Hannah's pre-existing critical thinking and problem-solving abilities in Computer Science, then to explore the ways in which she uses these competences when necessary. Finally, I recount the way in which her critical thinking develops over the course of the project, from both my observations and her own self-reporting. Woven through all of this are Hannah's self-reported beliefs regarding the importance of logic in terms of programming, which makes for what I hope is a fascinating and compelling account of her learning.

5.7.1. Hannah's thinking skills at the start of the project

As has already been mentioned, Hannah places a high value on the type of logic that can stem from and is critical to learning to program. Curious to know what this looked like in terms of problem-solving when coding, I asked Hannah about her process for fixing any bugs in her code (18.03.09 lns 51-57):

> Hh: It's basically it's literally sometimes it can be you missed a semicolon at the end it's so small that it will take you ages to find it um but the way I do it if the code doesn't work I will go to the top like an algorithm go through it and kind of just play it through in

> my head and see what doesn't make sense sometimes I'll bring someone else over cause they might cause it's my own code someone else's eyes might be like 'oh it's just right there' and cause obviously they can notice it easier so it's kind of if it doesn't work, just work from the top and just go down it again it's usually just something stupid like a semicolon or you've written the wrong syntax so yeah

There are two interesting points here about Hannah's process. The first is that she explicitly compares her problem-solving protocol to an algorithm. This along with previous statements suggests that Hannah believes that the sort of thinking that is required to create code, and the same 'logic' by which computers read the code, is useful for debugging her code as well. The second is her apparent willingness to rely on outside assistance in finding errors, which boded well for her attitudes towards teamwork as part of the upcoming project.

In regards to the teamwork aspect, Hannah was from the start determined that her group all contribute in some way, but she did have fairly definite ideas about how she might best allocate certain programming tasks (18.03.20 lns 31-45):

> Hh: Uh well Matthew is quite good at thinking up of ideas for things so they were kind of giving us different demos and examples…so Matthew would probably be able to think of quite an efficient way to do that… I know quite a lot about the actual JavaScript and code so I'd probably be working mainly on the JavaScript and because Jane's only just started looking into programming itself we're probably going to get her to I'm going to teach her a bit of programming so she can help cause HTML is probably easiest to start her off with so she could probably build the actual like layout… we'll probably all end up doing bits and bobs but mainly something like that

Particular sections of this exchange were also quoted in section 5.5 regarding Hannah's belief in programming logic and how it might be developed. This portion, however, provides more insight on her beliefs regarding her own and others' programming abilities and the potential for their development. Hannah feels she already has most of the JavaScript understanding she will need to complete the project, and has a strong level of self-confidence relating to her abilities there. Hannah's sense of practical thinking (Fink, 2013) is on full display here, as she is planning not only in terms of what needs to be done, but who can most effectively do it.

Hannah's practical thinking was put to the test in other ways in the early planning stages, not only in terms of personnel allocation, but in terms of reconciling what needs to be done with how best to do it. By the following Challenge session (18.03.21), Chris had joined the team, and immediately joined the planning efforts, with the result that a full mock-up of their intended product was possible (Figure 5.4). Hannah was primarily involved in advising which features were possible in KeyLines, based on her experience, rather than exploring creative ways in which to put together those features.

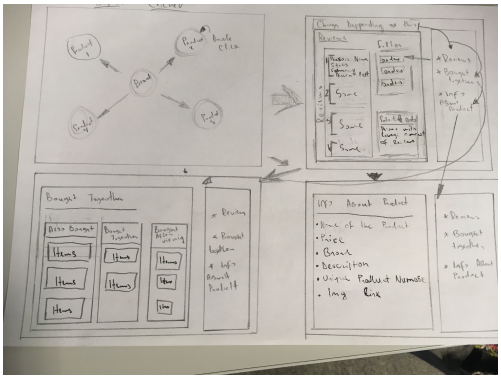

Figure5.4. Initial design sketch produced by the group on 18.03.21

In our follow-up session shortly after the initial product design is generated, I did ask Hannah about some of the more creative elements of the design process. As a means of triggering her process, I provided Hannah with data prepared by Gabasova (2018) as part of a similar project involving a social network based in the Star Wars cinematic universe. The first thing I offered Hannah is a screen showing the data in linear form: the names of each character, and after their names a list of numbers representing scenes in which they had dialogue. When I asked Hannah to scroll through and think about where she would start, she suggested the following steps (18.03.22 lns 86-89, emphasis added):

> Hh: Sorry I've [inaudible] it's obviously the names I'd probably make into nodes and I'd link characters that have obviously I can't really tell characters that have been in the same scenes as each other but just looking at the numbers like that it's like okay um **I'm not sure if there's a way you can tell the computer to find the same number if you know what I mean**

Hannah suggested the use of the characters themselves as the nodes, but finding links she felt would be a bit complicated given the sheer volume of data. Hannah's suggestion, to tell the

computer to pick out the same numbers (thereby identifying instances where two or more characters speak in the same scene) not only reflects how the final product was created by Gabasova (2018), but also predicts a method Hannah herself will use later on in her own project, though at this point she is unaware of the specifics of her project and thus the eventual necessity of such an action. It emerges in the context of her own project the following week, as she and Chris worked to extract usable data from the files they were provided (18.03.29 lns 7-18, emphasis added):

> Hh: Uh it's a bit like cause obviously we had to wait first for the data to get finished and then they can analyse it and design it um but while I've been doing that I've been familiarising myself me and Chris with the actual coding for making combos and stuff like that uh which we were both kind of struggling with last week because when I did work experience there they didn't give me data to work with I had to make my own so obviously I wasn't going to make 4,000 lines worth of data I was only going to do about like 20 so I was only working with a small amount of data so when I was coding them to do things I would just hard code it or instead of finding common links I just wrote all the separate nodes I wanted within a combo
>
> R: Okay yeah yeah yeah
>
> Hh: Um and now with this it's a lot different **you have to somehow write um a line of code that will reference to all of the bits of data that have something similar within them and then pull it out instead of writing each separate one like I did**

There was little change in her proposed method of calling the required data from the hypothetical situation the week prior to her plan for her own project here. Hannah was becoming more aware that her previous experience has not prepared her for every situation, as her data sets were drastically different in her work experience. She began to realise that she would need to develop new skills to complete the task set before her, specifically in managing large quantities of data.

5.7.2. Hannah's changing thought patterns

Hannah was quite willing to reflect on her growth and because she intends to make Computer Science her career, she has a tendency to relate work done in Challenge to concepts touched on in her A Level course. One of these concepts is the concept of big data*. Hannah believed that, given the additional steps she had to use to analyse and make use of this Amazon data, it qualifies (18.04.17 lns 57-67, emphasis added):

> R: Um how would this process be different if the assignment had been to include all of that data?
>
> Hh: I don't think it would have been any different because obviously it doesn't really matter um that much from the size obviously it it matters from being very small from what I've dealt with before to being very big but if it's any bigger than what we've got it would still be the same **it's just finding the syntax to call similar property they all have and it does the computer does that itself** so it doesn't matter how big it is we've just got to find that syntax for it basically
>
> R: Okay so once you get to a certain threshold like once it becomes big data it's pretty much
>
> Hh: Once it's too much to handle typing it all out individually um then that's when it's classified basically as big data so it doesn't matter how big it is after that state you've just got to find that line of code um to to be able to call it

Hannah certainly engaged in some reflection here, and quite competently identified the issues she had been facing and the solutions to them. However, the next day her instructor revealed to me that this type of project does not qualify as big data, because the classification is more complex than simply quantity. Despite the oversimplification on Hannah's part, it did suggest that Hannah was thinking about this project in terms of an opportunity to apply or develop conceptions useful to her day-to-day coursework.

Hannah was not exclusively focussed on expanding her programming skills, however. Hannah had also started to integrate multiple types of thinking, with her thinking often being done from the perspective of both the programmer and the creative director (18.04.17 lns 171-182):

R:...if you were using this data to try to predict future purchases what is the most important piece there?

Hh: So as I said earlier you you'd have a product and if it's constantly getting bad reviews then you know 'okay umm I need to kind of do something about it' umm so you could use red colour coding or maybe if everything's red hide that node then changes red or sets off an alert cause you can have glyphs that are exclamation marks and then they can notice okay this isn't really selling as much as I thought it would cause you could have some sort of like 'if' statement say if this product isn't being bought or reviewed on this many times in this time period then set an alert and then they can obviously realise 'okay I'm not getting as much profit as I usually do umm how can I change my product in the future so I can improve' and that can help you sort that problem cause you might notice too late and then be in debt you know problems there so yeah it will help you realise problems within your network a lot sooner

Here, Hannah showed evidence of creative thinking in terms of design features that can best fit the available data (such as colour coding or glyph alerts[40]) while simultaneously considering how best to code them, evidence of practical thinking. That this was occurring is not surprising; Hannah and her team had been regularly making efforts to evenly distribute tasks, and to get everyone involved in or at least aware of all aspects of the project.

5.7.3 After the breakthrough

Hannah remained predominately a programmer as the project moved forward, and as the project passed its mid-point, she finally had a breakthrough with the code, solving the issue she'd been previously having with calling the data (18.04.26 lns 3-17):

Hh: Uhhh so our biggest problem that we wanted to deal with was be able to know how to grab the data we want to be able to do something with it and the thing we wanted to do was combos um so they helped us through the email that one of their other um colleagues

[40] See preceding quote for Hannah's explanation of glyph alerts

sent us through the iteration the loop to go through all of the data take out which ones are reviews and put them in an object

R: Okay

Hh: And in that object it had a list of all of the different sorts of* ASIN ids and next to that there'd be an array that would contain all of the reviews that had reviewed on that product uh so we got that sorted which is organised and everything separated them based on the product that they've commented on so from that we could literally just reference the array put it in and create the combo um which the guy helped us with so um [Cambridge Intelligence employee] the woman in the pink jumper helped us with the iteration process of it and then the other guy who I'm not sure what his name was umm helped us with the combos and so that's all basically sorted now and then on the Trello as you can probably see in the to-do list there's so much to do now that we are able to get at that data and do something with it so we've got quite a lot of stuff to do next week

By this point, Hannah had a much more complete view of the issue her team had been facing, due in part to her own research and in part from the guidance received from emails to the Cambridge Intelligence team. In the end, the solution was a relatively simple one, as Hannah was quite willing to admit (18.04.26 lns 18-23…38-46):

R: Okay um it looked like it was something relatively small that they were able to fix

Hh: Yeah

R: Like some you had something on one line that you needed to separate something out

Hh: Yeah so we had uhhh for the iteration process an 'if' statement and it had two arguments within that 'if' statement and all she did was split it into two separate statements and that was it…

R: Is there a reason that this particular type uh these two types of statement would have had an issue, was one dependent on the other or?

Hh: I wasn't well I wasn't really sure at first cause basically we had 'if the node we are looking at is a review and the object doesn't have it already, put it into the array' and then

> all she did was go 'if the object is a review' and then another one saying 'if it's not in the array put it in' so then if it is a review uh but it is in the array it just skips past that but what it was doing I think was if it's part of the review it was making a new array anyway so it was making a separate array for all of them instead of checking the statement twice it just did it in one I think that is what she was trying to get at with it

Hannah did not merely allow the experts to make the changes, she followed closely what they were doing so as to better understand what to do if she again faced a similar issue. She had again, however, oversimplified the solution; while splitting of the statement did in fact solve the issue her team had been facing, Hannah has overlooked the importance of the actions surrounding the splitting of the nested if statement. Among other things, the expert "changed the ASIN number from a number to a string" (18.04.26 ln 25), and may likely have cleaned up the syntax at the same time. These changes, largely disregarded by Hannah here, may have ultimately been as much a part of the solution as the splitting itself, as splitting such a statement is largely a cosmetic solution (Else, M., personal communication, February 15, 2019).

As Hannah had stated early on, issues can arise from something as simple as a missed semi-colon, so the possibility that she overlooked such a change here is possible as well. Regardless, the changes made here represented another shift in the project, as well as the dynamics of the group. With the most pressing issue sorted, Hannah's thoughts once more turned to planning, and she actually relinquished her Head Programmer position for the following week, in favour of working with the report and allowing Jane some programming time (18.05.01 lns 37-46):

> Hh: I think so yeah because obviously if I don't know what's in the report and someone asks me a question on it I'm a bit like uh no idea I think report writing is important for everybody everyone's gonna have to do it at some point um so if we all partake in that it will obviously help us develop our skills with that as well and with the presentation part we all have to present so we all have to know what we're doing what how with the report and everything so yeah it's really important that we all have an input into that
>
> R: Okay umm and then you will still be doing a little bit of coding tomorrow is that the plan?

> Hh: Yeah yeah it is everyone's gonna cause Jane hasn't done any coding yet Matthew kind of has he's been looking at the code but not actually coding anything umm so everybody's going to have the chance to do everything tomorrow which will be good.

Hannah and her team were purposefully putting themselves in situations in which building multiple competences is necessary. While Hannah had already shown evidence of this (see above), it is clear she felt she can still make improvements to this area by editing the report and building another transferrable skill. She also believed that having the programmers doing some of the reporting will add value to the report itself, most likely in the form of refined detail.

As the team went to put final touches on the project, Hannah had returned to her role as Head Programmer. Jane's attempt at coding had not produced a successful change in the code, and so Chris had taken charge while Jane returned to the report and worked with Hannah on that. Following this, Hannah seemed to focus more on using collaboration more to meet targets than she had previously (18.05.11 lns 9-17):

> Hh:…now all our reviews are colour coded based like on the rating that they gave umm and then I've also the other day made brand combos umm within those brand combos are umm the products umm but it's not the actual product combos that are inside I've got to combine them now umm so we've got loads of brand combos over here and then loads of product combos over here and they've just kind of got to be morphed together umm we did try and attempt to do that link thing I was talking about linking the reviews if they're by the same person uhhh but I started doing that and it was quite complicated so I think Chris might have to help me with that cause we usually can work quite well together when we find a problem…

As the project reached its conclusion, Hannah had accepted that teamwork and collaboration were her best options for hitting her remaining programming targets, such as creating links between her now completed combos. While certainly one might assume she had planned all along to engage in some form of collaboration based on her preliminary interviews, Hannah had by this point abandoned much of her expressed beliefs regarding her elevated status within the group, and completed the project as an equal partner with the rest of the coding team.

5.8. Hannah's reflections on the project

As predicted, many of the programming tasks in the final sessions were copying and pasting from demos the team liked, so Hannah's programming skills and critical thinking changed little between the combos becoming functional and the end of the project. Reflecting together just before the final presentation, Hannah admitted there were several points where she felt as if there was pressure on her to understand things beyond her current level (15.05.15 lns 213-224):

> R: Like you said it's very different than the experience that you had with your work experience because the data sets are so dramatically
>
> Hh: Yeah very different which is it's weird I feel like if someone's struggling on something [Instructor]'s like 'just ask Hannah' and they'll come over and I'll be like 'I don't know' but I feel like I should know and I keep up this like thing and I just don't know half the questions they ask me cause I think umm before I even knew how to do combos Kate umm not Kate Phoebe asked me how to do them cause she saw it in one of the demos and I went 'Phoebe I honestly do not know' I know the syntax cause you just copy it from the API reference* but I don't know what to put in the id section cause I don't know what the products' ids are and umm so yeah that was kind of the cause obviously with my code I knew what all their ids were it was literally just 1, 2, 3, 4, 5 like I could literally put it in but the ids for these are just so much different and it's it is not as easy as you think it is so yeah

Despite having been presented as an expert and feeling that pressure to succeed, Hannah was near the end able to justify her struggles in terms of her actual versus perceived prior knowledge. This being said, she does feel as if progress was made (18.05.24 lns 414-431):

> Hh: I feel like more of an expert now I feel like everyone's more of an expert now um I yeah it's really difficult cause obviously I didn't realise that with much larger data sources it's not done the same way… I come walking in going 'oh this Challenge is going to be easy I've got this' and obviously I'm seeing data I don't know it's like 20,000 lines long and it's like 'okay right this is different' um but obviously I I recognise the API I

> know how to do that *chart-dot-combo-dot-combine* and then obviously when you get that 'what ids do I want' that's when I hard-coded it I went 'person 1, person 2, person 3' done but with this it's obviously like I don't know what products have that thing in similar therefore I need to go through all the pieces of data in like a loop and pick out the ones that have that similarity put them in a variable that's what I want to combine that's the bit that I didn't know so I knew the *chart-dot-combo-dot-combine* I knew like the *chart-dot-create links* it's just what bits it's how to drag that data and put it in that's what I didn't know so that's now I know how to do that now I'm like 'now I'm an expert'…

As she reflected on her progress through the project, Hannah no longer measured her expertise against her peers, but against herself from the beginning of the project. While she had gained specific skills and has a better understanding of particular elements of the coding process, she felt as if the class as a whole was forced to make large gains in their application of programming knowledge as they progressed. The biggest changes to Hannah's thinking process was not necessarily in terms of improvements in just this area, but rather the integration of her thinking. After working on the report, Hannah's thinking concerned not only what was possible, but why it was necessary. This was implicit in several quotes above, and also made explicit during team meetings in the final weeks as the team made the final list of features to complete. She also considered more the contributions of her teammates, peers, and instructors as she worked, viewing herself more as a teammate than a team leader. One of those teammates, Jane, was also a participant in this research, and it is her story to which the next chapter is dedicated.

CHAPTER 6- Jane and the computer science project

The narrative of Jane's experience is quite unlike Hannah's in many ways, as Jane came into the project with a very different existing skill set and background. She took on a different role in the project, and therefore had very different struggles and triumphs. Her story is important in this regard, as it offers another perspective of the same project, even within the same group working towards different aspects of the same goals (the product and report). Jane's focus was on chronicling the team's journey and selling their product, but also on helping to envision the client to whom they would be selling. Her experiences in this, like Hannah's, provide value not only in terms of being unique learners in a project of interest, but in providing a contrast to one another. Jane's story, as a budding creative director and project manager, offers the perspective of the non-programmer in a programming-based project and sheds some more light on the diversity of roles such a project offers.

6.1. Jane's background

Jane is the only participant with whom I had an existing relationship, having met with her several months previously as part of the pilot study. At the time of our first meeting, Jane was a 16-year-old student taking A Level Biology, Chemistry, and Maths with the aim of pursuing studies in medicine. She is also the only participant to have been at CAST for her GCSE's and had sufficient time to form opinions about the school, so our meetings several months apart should not have appreciably changed her perspective on either CAST or the experience of Challenge. These views were on both occasions quite positive, as she appreciated the small class size during lessons, and the opportunity to pursue new areas of interest during Challenge. She expressed on several occasions that she believed these features would benefit her in her plans for the future. What is interesting, however, is that in our second meeting just prior to the start of the Computer Science Challenge, Jane indicated that her career aspirations had shifted somewhat (18.03.01 lns 65-75):

> J: … I still kind of want to do medicine but I'm also like opening up wider so like having other career choices that I'm also really interested in
>
> R: That was a big change because you were pretty-

J: Yeah!

R: Pretty set on that before what happened [some talking over]?

J: I don't know maybe I fel- I was discussing this with a friend yesterday actually I was like maybe it's just for security reasons like for me in case like for A Levels so it's not so much pressure on me that I also have something to fall back on

R: Yeah

J: You know what I mean? It so I don't feel like if I don't get the A Levels[41] so I don't feel so stressed out about it, I've also got other stuff I'm really interested in

Previously, Jane had been quite optimistic about her studies, referring to herself as a good student, who listened in class, completed work on time, participated in class, and so on. While the above exchange might suggest that Jane felt less confident in herself, it is clear throughout the CS project that she still felt she possessed many if not all of the qualities she valued at the start of the year. Rather, the impression she gave off at the start of the CS project is one of pragmatism rather than pessimism. As she progressed through her A Level studies, she was more aware of both the challenges and opportunities that may lie ahead, and the importance of developing a diverse skill set to be prepared. This seemed to carry over to her views of this new project, where she did feel that while it is a new challenge, she did have some of the tools to succeed based on past experiences (18.03.01 lns 101-105):

J: I've only used Small Basic and Visual Basic so it's like really basic stuff compared to Java [sic] but it uses like similar stuff it the basic kind of technique of everything like coding it's still really similar cause yeah cause I did GCSE in Computer Science

R: So you'd have to have done some of it already

J: Yeah. So I already know the background

[41] In the UK, different courses within the same university may have different admission requirements, with those for Medicine often being higher than those for other degrees

At this early point in the project, Jane had not yet seen the objectives for the project, or the software development kit (SDK) that they would use. However, she did anticipate that she would be involved in the coding to some extent, as it is a Computer Science project. She, like Hannah, also held the belief that there is a certain logic common across all programming languages that can be transferred from one to the other, so that might have proven to be of some use. Because the first several interviews (18.03.01, 18.03.09, 18.03.12) took place before the project was launched on the 14th of March, there is not much more that she could determine at this early stage. Jane, like all the students, had to wait to find out the specifics of the project and of her group to determine where she will fit in.

6.2. Jane as a Creative Director

Because Jane was entering the CS project as one of the few individuals not enrolled in the Computer Science A Level course, she might reasonably have felt at a disadvantage in terms of her role within the project. As previously discussed, Jane had completed a GCSE in Computer Science and so had a limited programming background, although she did not feel it was as extensive as many of her peers. She did, however, mirror Hannah's belief that she would be able to quickly pick up enough of the basics to be of use to her team (18.03.12 lns 56-64):

> R: Um and then do you feel that there's a certain style of thinking that you have to have to really be able to code effectively?
>
> J: Yeah. I think a logical thinking like to be able to know if I do this it won't work or it will work then try to see like as well like in the future like when you're coding some more so definitely very logical
>
> R: So you almost have to think about all the steps that you're going through
>
> J: Yeah
>
> R: Um and then do you find that's something you do naturally?
>
> J: Yeah I naturally kind of think of all the steps yeah

Both Hannah and Jane believed there is a particular type of thinking necessary to be successful as a programmer, referred to in both cases as 'logic' or 'logical thinking'. From various exchanges on the topic of this sort of thinking, it most closely resembles the definition of computational thinking put forth by Wing (2006) wherein it is not knowledge of programming or languages, but a style of thinking that allows for the most efficient solutions to problems.

This logical thinking Jane referred to was necessary not just for her ability to program, but her ability to contribute to the long-term planning of the project. There was some evidence of this logic in her early images (Figure 6.1) of her team's product, following the launch of the project (18.03.20 lns 26-42):

> R:…can you kind of sketch out in your head what you're thinking or if you've got a design in mind?
>
> J: [drawing] okay so it's like reviews and everything uh let's think oh reviews for Amazon and then have … like don't really know but if there's a way of rearranging it I would definitely put like uh good and bad reviews as a way you could the amount of stars like and I'd have like keep it simple like they did, like nothing too messy but have the like the products with the most reviews on it as well so like [writing] (products) and then not too sure but kind of like reviews and then goes off to another product that the person who reviewed it has bought and then have like a link that way
>
> R: Okay
>
> J: So like whether you just think products together by reviews people who have done reviews for both or you link reviews together by like products and then like the link would be products cause somehow you've got to have something that's like the link between that or like the person could I haven't really I've thought about it but still like all the ideas going through my head so like the person like and then they have like products they bought by reviews [inaudible] review like that but yeah and then they'll just have reviews coming off each one and then that

Figure 6.1. Jane's initial image of her product

product will be linked to other peoples' reviews like that

Here, Jane was working to come up with links that maximise the usefulness of her product to a potential viewer or client. There are hints of several features that will be incorporated into the final product, such as filters, review counters, and identifying reviews as good or bad. Jane also seemed to believe that the most natural way to link products is to connect those products that have reviews by the same individual, making the people the common property from one product to the next. At the same time, she was considering flexibility here as well, suggesting the reviews themselves might form nodes, and the products form the links between reviews/reviewers. That there was still such a range on this suggests that Jane and the team had not yet solidified their image of the hypothetical client, which will be discussed further in the next section.

By the following week, Jane's group had expanded to include Chris, who joined Hannah in a primarily programming capacity. This made it less necessary for Jane to pick up any coding tasks, and so she settled into her role as designer and recorder. She began work on a digital mock-up of the end product (Figure 6.2), which shows several changes from the initial design sketch (Figure 5.4, in Hannah). The most noticeable changes are the brand combos, here labelled generically, and the glyphs atop each combo. The combo feature was one frequently championed by Hannah, and the glyphs were a feature both Hannah and Jane felt was important to include in their work.

Figure 6.2. Mock-up of website created by Jane as part of the Power Point presentation. Further detail provided in Appendix B.5

Half term vacation split up the project, and when the team returned, Jane came back motivated to move forward with the project having gotten some distance from the project over the break. We met before the first day of the project for a brief catch-up, and to consider some of the practicalities the team might now need to be considering. One of these points concerns the quantity of data; what would change if all several million reviews had to be used for the project?

> J: Mmm that well probably you'd have to like maybe create like a program or something to organise the data I don't know organise it a bit more and you won't be able to have maybe as man- it'd be really hard I think you'd have to have maybe something to program or something to look through all of it so you could find certain categories and products and see what there was you'd have to have something before you use it to filter it down a little bit just to see what there is to work with and it would take a lot longer and be very time consuming and boring…I think it would be quite hard… I think it would just be quite messy is what even though even with the kind of like model the KeyLines thing where you using I think it would still be horrible to uh it would be horrible to look at and use (18.04.16 lns 19-30)

Jane's solution here may sound familiar; it is quite similar to the strategy Hannah had considered on multiple occasions both in hypothetical scenarios and within her actual project. Both girls

were thinking in terms of efficiency; given their time constraints, it was absolutely necessary that they find a way to sort the data more quickly than they could do manually. Jane's motivation was more directly tied to such a program's impact on the design and user experience than the practicality of coding in such a function, however.

In the end, while they did not have to use all the data, Jane's group did come to a point where they found it necessary to consider adding additional data (18.04.27 lns 60-67):

> R: Okay um and then I think I know the answer to this one but um going ahead and it looks like the decision's been made to add more data?
>
> J: Yes
>
> R: Umm and what is that going to accomplish do you think?
>
> J: I think it's just going to make it look like there's more and we can see more connections cause at the moment the combos even the combos might only have one like the brand might only have one product to it so it's a bit bare and we want to make it just a bit bigger and have more stuff in the combos and to make it have more links so you can really understand stuff a bit more

The successful conclusion of the combo issue (§ 5.6.3) just after the project's mid-point brought out a new issue: the products were nested neatly within brand combos, but there were no reviews in common to make links extending from one brand combo to another. While Hannah and Chris were responsible for the actual addition of the data, Jane took an interest in terms of deciding which categories from which to add, and considering what impact such data might have on the client experience. It also opened up time for the team to focus on additional elements of their project.

Jane and her team near the end of the project were able to turn their attention to an aspect of their project that had previously been, of necessity, neglected. The branding of the product remained quite important in the team's opinion, and several efforts were made to make their layout unique and easily identifiable. Jane also added some additional marketing touches (18.05.11 lns 205-214):

J: So well actually for like a like I was just working on it a little bit the Power Point this morning I was just with my friends and I was literally like 'do you prefer looking at data this way' like showed them a KeyLines demo 'or do you prefer looking at it this way' and showed them all the data in a line like we had and they're like 'KeyLines demo' so now I've got like a statistic like 100% of people feel like prefer that and some of them were like 'oh it's so much easier to see the links between stuff how it all interlinks' and then I was like 'two out of four people think that' you know having statistics in there really helps with selling and marketing so I was had some of them and then also kind of just we've got a good kind of scheme going on our we've got a purple Power Point and it matches our purple HTML like purple and grey HTML for the page umm selling the intelligence we're kind of just marketing like in the report it just says like how you see links between can't remember like just you see the links between stuff and then it's just a lot it's easier and quicker to analyse data if you can just see the links than having to scroll through and look just try and memorise stuff and see if it links in there yeah

The team chose a 'regal' look to their product, changing the colour scheme and layout so differentiate it from the standard KeyLines template. They felt that this would help to distinguish them even further, beyond the boost they felt the combos would give them. Jane also picked up on the idea of gathering statistical support to influence potential clients. As can be seen in the final presentation (Appendix B.5), these statistics related to the relative ease of understanding and the user experience, and Jane found them to be an excellent selling point.

Our final interview sessions naturally took a more reflective turn, with Jane considering her role and how that fitted within the team dynamic, feeling that "…we've kind of just been sticking to like our like just each doing their own thing and then doing it together at the end" (18.05.11 lns 191-195). While she did contribute in terms of direction and helping to select the team branding, she felt as if everyone had their own 'place' within the project, and rarely strayed from this. This being said, Jane did not feel as if any role could be successful in isolation; just as the programmers needed a template from which to plan, she as the creative director needed to have a basic understanding of what was possible (18.06.11 lns 345-354):

R: Okay um so of course the creative director you know comes up with the vision of things they want done um but how important is it for that creative director to have an

understanding of the programming capabilities like how how literate do they need to be in the programming languages?

J: I think it a little bit you can't just be like 'oh do this make it fly' do you know what I mean it's not gonna do that so you can't like it will put a lot of like if you want someone something like you give and idea and it's not they spent ages doing it it's not ever actually gonna happen cause it's not possible

R: Mm

J: So I think it's important to have an idea of what you can do and can't do within code

The meetings that Jane and her team held were not only important for maintaining morale; they also served the vital purpose of comparing notes to see what was feasible for the group to complete given their timeline. Jane believes that it was necessary for her to consider the functionality of KeyLines before making decisions; as can be seen in their presentation (Appendix B.5), research was an early focus for the team. In the end, while Jane did not do much if any of the coding that made it in to the final product, she did gain an understanding of what was possible so that she could better serve the team in her role as creative director and chronicler.

6.3. Jane's evolving image of the client

When the team started to plan out their product, they did so with a particular prompt in mind: they had to sell the intelligence that could be gained from their network. This was because, according to Jane, it sounded nicer than the other option, which was to sell the solution to a problem that could be picked up from the data. While selling the solution would have presented its own set of challenges, the biggest component of selling the intelligence was understanding who they were selling the intelligence to. This determined what spin they would put on all of their work, which they hoped would also give them a target audience. In the early stages, Jane was predominantly considering what might work in terms of what she personally has found useful (18.03.20 lns 56-59):

J: I look for reviews when I buy a product I look to see how many reviews it gets as well because it's got no reviews I'm more hesitant to buy it I will look at reviews when I'm buying when like I'm not sure a product like I want something but I'm [not] sure what brand to get then I'll look at reviews I will yeah … that's definitely a big point

This interview was conducted immediately following the official launch of the project, so Jane and her team had not yet had much time to consider what intelligence they will be selling and to whom. However, one of the first angles she approached her planning from was what she as an Amazon user found most valuable in terms of intelligence. For her, she felt both the quality and quantity of reviews are important for determining a product's worth.

By the following week, Jane had given more consideration to who exactly might have interest in the intelligence they have to sell. Her first thought concerned Amazon directly, and how they might use intelligence gathered from traffic on their website (18.03.29 lns 105-115):

J: So you can link the products by what other people have bought and then that would be able to for Amazon if you sold it back to them for instance then they would be able to see oh so this product was bought a lot with this product we should advertise it on like the page with it together and then it would give you know then people would be be easier for the customer and they might even get more people buying it or if a product's got really good reviews for like one certain brand they might like drop another brand you know

R: Okay

J: Or know which brand's the best and then I would just yeah probably sell it that that way just back to I think that would be most useful for Amazon

R: Okay

J: Or brands just to see like their competitors and stuff

Here Jane was exploring two possible options. The first was to help Amazon itself figure out which brands are performing well together, as a means of enhancing their 'bought together' options. We discussed their pre-existing algorithms for determining this information however,

and as she moved forward the second option, allowing brand competitors to see how existing products for sale are faring, gains greater focus.

Jane did have one idea here that, while rarely mentioned again, was quite an interesting one: creating a tool to find the intelligence, and then selling that on, rather than the intelligence itself (18.03.29 lns 121-125):

> J: … like it could not even be Amazon you could say it was like eBay or something you know and you could sell it to them and then they could just input their data to the thing but you've already got all the options there all set up and everything and they just have to put the data in and that's you could sell it that way

What Jane was proposing here is very similar to the Cambridge Intelligence business model: generating a template and then selling that on to be customised by the client to pursue their own aims. The service they would essentially be providing then was determining which features would be of use and reducing the programming time the client would need to spend to get usable results. While this idea was dropped after this session, it is an indicator that the group was trying to be as flexible as possible in identifying a client image.

After the half term break, Jane's image of the client was connected more to the practical side of her group's programming. We started discussing the idea of adding in additional data sources, and Jane did consider this to be a good idea in terms of what it could offer her clients (18.04.16 lns 51-57):

> J: Well then you'd just be able to see the link between the other categories like mainly and then maybe that would give you some more insight on what people other people are buying and reviewing and everything because at the moment you just get what they're buying in that category or what they're viewing within that category when there's all these other products that could even be linked to the product but you wouldn't ever know

Jane was feeling that the lack of connections might limit the intelligence to be collected from the data. This became more apparent when the combos were completed and stood isolated from one another, but the concern about the lack of connectivity existed even before they began to

visualise the data. Jane also considered what the intelligence implications of additional data sources might be (18.04.16 lns 91-96):

> J: Yeah so what with the data that we're doing I don't really know much but if you were doing big data set then you'd be able to see what categories they buy the most from and then be able to tell 'oh they're more likely to maybe buy this right now' or like buy this or like buy more stationary or something now do you know like if there's a stationary category if they buy loads of like pens or paper and stuff you predict 'oh they're gonna buy that again' cause they've bought it the most often

Here, Jane again mentioned the idea of adding more data, but in this case specified what impact this might have on the potential client. This would allow the focus to be not on the products but on the individual consumers, and might allow her clients to predict *their* clients' behaviour and target their sales to them based on that information.

It certainly seems as if Jane had in mind a particular client at this point: a company whose product(s) is sold on Amazon, and is hoping to increase sales. Perhaps this was an obvious one given the data, but it is still of use to the team as they try to navigate the decision-making process (18.04.20 lns 69-75):

> J: …our assumptions are we know that we think it's gonna take us like blahdy blah amount of time or assumptions is the client wants one of these options do you know what I mean it will be useful for them this option will be useful for the client then the risks are um what was it oh yeah the timing that was was a risk as well about the risk is that we're not gonna get it done on time cause we've planned we've got too much to do or we haven't kept on timescale and stuff like that and the risks of not yeah that would be it

Jane's comment about assuming their product fits the clients' needs reveals more than perhaps it might initially appear. At this point, Jane was thinking of the client as an independent entity with a decision-making process of his/her own, rather than as an uncritical extension of her own thinking. This as it turns out is a deliberate move on her part (18.04.20 lns 79-83):

J: Yes, yeah but instead we're having to think how do like yeah but it's also for the mid-term report having like I mean I don't know if we had to add in like a client in there but it just seemed kind of helpful to have more of an objective on why we're doing this you know what I mean and in the original piece of paper it said for a company like selling it and stuff so it will work it will be fine

Despite never being explicitly instructed to add in a client, Jane and her team felt that the best way to move forward was to create one and bounce their ideas off what they imagined this client's response might be. They did not limit themselves to a particular client, however, with Jane suggesting that "…we're trying to get the most options possible so that it can go for a range of clients" (18.05.18 ln 160). This had not always been the case; as was seen in earlier weeks, Jane had a single client in mind, but as time went on she has started to see the value in creating a diverse product (18.05.18 lns 171-179):

J: I thought it was mainly going to be based on like one client type and wasn't really too sure how you'd like how you'd sell it to them and which one to choose cause we're selling the intelligence but then it kind of like when I have to it's a broader range it's better in a way

R: Mhmm

J: If you have that and then yeah it's changed a little bit like the how it caters like is that the right word caters towards them yeah

R: Okay

J: It's definitely between being more kind of straight like yeah this is how it it's gonna be useful to them

Jane didn't consider the flexibility to be splitting the team's focus. Rather, it allowed them to think about the features they did select from multiple angles, thereby enhancing their team's ability to sell their product. In the end, according to Jane, this strategy paid off. Her team's product was selected by the judges to be the best overall, much to the delight of the whole team.

While Hannah believed that the combos, being the newest feature for the company and her team being the only one to successfully master them, was the biggest factor in her team's success, Jane felt it was more on the creative end that her group really shone (18.06.08 lns 7-11):

> R: Um what do you think the biggest factor for those judges was in making that decision?
>
> J: Well we marketed it more towards like having people we were selling it for while that's what they told us anyways we had goal and how we had like a client and how we were gonna like make the product for them and not many other groups actually did that which was the whole initial kind of question is selling the intelligence and we sold it

I would not suggest that either girl was wrong in her assessment; the features that won the day would not have been successful without a client to whom to sell the intelligence they generated, and the client image would have had little impact without a quality product to sell to them. It is however clear that both girls took pride in their work and their contributions, while still valuing the work of the other.

6.4. Jane's fascination with trolling

Most internet savvy individuals will be familiar with the term "troll" or "trolling"; it is in common use applied to individuals who make deliberately inflammatory statements online for the purposes of disrupting a conversation, or to influence individuals to behave a certain way. This use of the term is almost as old as the internet itself, and it is not surprising that I found it to be a part of Jane's vocabulary. While the term often refers to individuals acting independently for personal amusement, at the time these interviews take place there is a tremendous focus on more organised trolling to influence the outcomes of major political events, such as the Brexit referendum and the 2016 US Presidential election (Jensen, 2018). Jane never addressed any of these examples directly, but she was quite aware of the potential impact of internet trolls on the behaviour of consumers. Almost as soon as she is provided the data and the assignment brief, Jane considered the detection of trolls to be one of the many applications of her team's work (18.03.20 lns 84-101):

> J: Umm … I dunno just really see what people buy with other stuff what people's reviews are for stuff if it's a good product or a bad product and then then we'll like investors will know like 'invest in this sections of something or like this product or' um yeah just see how people like products are linked from reviews even like you could see like if somebody's just trolling and always leaving bad reviews you know like you could probably catch that through one of these database type things cause if you put like if the same person's leaving a bad review for so many products then that's not right otherwise unless they only then again that could also be like people only leave reviews if it's a bad product and they want people to know that or something … couldn't it I don't know… you'd have to be able to like filter them all down you know if like the sections good/bad reviews like maybe be able to click on one person it just comes up with all their stuff and like the amount of reviews they've had… and then it's just easier to tell straightaway how many like how visualising it yeah

Jane differentiated here between intentional trolling and the sort of bias that she believed is inherent in consumer-based reviews: people are more likely to comment on products they found extremely good or extremely bad, with far fewer reviews expressing a more neutral viewpoint (Beaton, 2018). Jane is right to be cautious; De Langhe, Fernbach, and Lichtenstein (2015) found that there is a "substantial mismatch" between the objective quality of a product purchased online and its perceived value from online reviews. Her clients could indeed find information from potentially trolling reviews to be of significant value, even if it is not entirely accurate.

Jane's planning continued to consider ways of sorting out trolls, as she did feel as if this could be particularly valuable intelligence for her clients. She and the team decided that one of the links they feel is important is the link between customers and all of their reviews, because of the insight such links might provide (18.03.29 lns 16-19):

> J: Yeah or you could see how many well the customer that have what they have reviewed and at a glance you could see if their reviews are all bad or if they're mixed or if they're good and if they're all bad then you can kind of work out they may be trolling or if it's all

> for the same brand, they could be also like working for that brand and leaving good reviews if it's yeah

Jane's assumption here was that most people would generally post a mix of good and bad reviews, so reviews that are exclusively bad or exclusively good would point to some sort of ulterior motive. Trolling was not her only concern; incentivised reviews were for many years a common enough phenomenon, and so her fears that this could be present in her sample are perhaps justified. Despite her concerns on this front, she still had a certain amount of faith in the objectivity of the reviews (18.03.29 lns 97-103)

> J: Well like how we could be able to use it so I was thinking that if you're so like I said earlier about people trolling and stuff and then also you could see what the most popular product is cause you could filter like one of the options could be like umm products down the side and this like types of products say like lightbulbs you know for instance and then you can click on that and it will just show the light bulbs up and you could see what the best brand of light or like what the most reviews best reviews are for the light bulb and that would be useful for Amazon or another option is what people have bought with that product

Jane believed that while some individual reviews may carry the bias of their reviewer, an average of the reviews may still provide valuable information. Jane also indirectly touched on the notion that the greater number of reviews a product has, the less weight a single undetected biased entry will have.

The topic of trolls came up several more times as Jane and the team worked on their product. The catching of trolls was not the primary aim of the project, but the team does feel that a method of flushing out biased reviews would certainly add value to the intelligence relating to trends in consumer behaviour. Trolling remained such an important issue for Jane that it did explicitly feature in the final sales angle the team settled on (18.05.18 lns 144-155)

R: Um so what is that final angle that you guys are gonna use when trying to see your product

J: So we're gonna do like for clients who have their product on Amazon and … also for clients who … are looking to put their product on Amazon so with the ones already on Amazon it's to look like um is the competition is there like if a product is being bought with their product and they're not producing that product maybe they should invest and produce that product so then people will buy it as well if it's getting bought with it or if there's like someone who's leaving bad reviews like just on their company brand like all of them then it could be like 'oh this person's just trolling us' and stuff like that and it's not they're not leaving reviews or bad reviews or even any reviews on any other brand and then for the clients who are looking to put their product on Amazon they can just see 'oh is this product with all these like product type they've all got bad reviews maybe I should like put my product on Amazon and people will buy it more because it's better'

As has been noted previously, Jane and the team kept a fairly flexible image of the client, but the main priority was to understand buying trends to determine the relative popularity of certain brands or items listed on Amazon. Because Jane believed that trolls or incentivised reviews could jeopardise the integrity of the collected data, she maintained through the entirety of the project that using their network to identify such reviews so they can be discarded in favour of a more objective picture.

6.5. The development of Jane's transferrable skills

In all the cases of all three participants, the development of transferrable skills was an expected and desirable by-product of their participation in these projects. In the cases of Hamish and Hannah, these skills were important but not the focus of their learning. For Jane, they quite early on became her primary target. While there are many examples of transferrable skills, it was important to me that I understand the type that Jane felt she could develop from this project, and which ones she most valued (18.03.16 lns 44-51):

R: …what transferrable skills do you really think are going to be necessary for this Challenge that would actually have applications for after the Challenge?

J: Mm I'd just say like planning a project that that's kind of the skill that's the skill I reckon I dunno um yeah teamwork's the everyone uses teamwork don't they it's a normal one um being able to communicate with your team I would that's another skill like to be able to like communicate in a way you get things done you know what each other's doing if you have good communication there then it just flows

Jane identified two primary skills she believes will be developed during this project: planning projects and communication. These are two skills often associated with project-based learning (Musa, Mufti, Latiff, & Amin, 2012), with teamwork, interpersonal skills, and problem-solving also cited. Because of Jane's perception of her role within the group, it is unsurprising that her focus was on the planning and communication elements.

6.5.1. Jane's communication and teamwork

I have already touched on the intra-team communication that afforded Hannah and Jane's team such insight into the work each member was doing, but for Jane, communication relating to the project was not limited just to those in her group (18.04.20 lns 8-15):

J: So to start off with I kind of just had cause I asked someone what they like what [Instructor] said to them to do and he was like just put in like what you've done, how you did it, what you need to do, and the difficulties you've had so I kind of did a basic thing of that and then I talked with the guy who came in I can't remember his name but somebody who works for ARM and he just gave me an example like let me look at an example of his and helped me with a more structured layout and it was like business objective and then the source of our code we put in the like we also put in kind of of like our like what we chose to do, how we're gonna do it, and then well okay and then what was it

Jane viewed her peers, instructor, and mentors as possible sources of information, additional teammates in a way. Because by this time Jane had established herself in her role as group scribe, she felt a responsibility to deliver a high quality report for her teammates. The preceding quote was from the last session before the interim report was submitted, and Jane certainly worked with the mentors and her instructor on format and general content, and communicated with each member of her team regarding progress in specific areas.

When the resolution of the combos problem created the problem of unconnected data, the team again took a collaborative approach (18.04.27 lns 83-89):

> R: Umm who's making that decision about which data to add and how are you guys deciding that?
>
> J: We haven't really talked like we haven't really talked about that section [we'll probably] do that next Wednesday but yeah maybe in next Wednesday we'll have like a like small meeting like we usually do and I'll like we'll discuss that probably but Matthew was the like the one who was bringing in all the data who was bringing in all the data so and then I think it should be a team decision but we haven't really thought about it too much

Jane and her group did not make major decisions without meeting as a team to ensure all of them had a say. Meetings at the start and end of each session, as well as when major decisions such as this have to be made, demonstrated that Jane's belief that teamwork and collaboration would be major skills necessary for this project was an accurate one. This was actually one of the areas where Jane felt her group had really perfected a routine (18.06.08 lns 392-398):

> R: … how important was the communication in terms of planning um what did you all do to communicate that in those early stages?
>
> J: Very important we used to kind of just have small meetings at the beginning and just said what kind of needs to be done like who's doing what all like then what we did do last week or what we need to finish and then we updated the Trello as well so everyone could look at it and then yeah so you could look at the Trello see if there's anything that

> or if you forget what you're doing or somebody wants you to do something like you can just look at that

All of these updates meant that not only did everyone coding know what the other programmers were doing, Jane as the recorder and report writer was aware of what was happening and when. While the report (Appendix B.7) glossed over many of the struggles the team faced, Jane did rely on this stream of communication to create as faithful a narrative as possible. What she accomplished is something new for her; Jane had not previously written a report of her activities in this manner (18.04.27 lns 152-154):

> J: So the mentors we got stuff about the report so like the layout and stuff cause I've never written a report in my life and so she was really helpful the woman who helped us and she just laid out the sections for the report quite clear and precise

This quote was from early on in the project, and never again did Jane explicitly mention that this was her first attempt at report writing. Whether this is because it ceased to matter to her, or she was too absorbed in other concerns is not readily apparent, but it is evident that in the end the combination of collaboration and guidance Jane received was sufficient to lead to a complete report. It is evidence of how Jane had worked to communicate not only within her team, but to convey the team's progress through her first ever report.

6.5.2. Jane's project management

The other transferrable skill Jane anticipated picking up as part of this project was project-management. This is different from planning a project, which was explicitly mentioned in 6.5, but further communication makes clear she considered planning just one element of the managerial position she anticipated finding herself in. It was certainly a reasonable expectation; the structure of the project (Appendix A.8) was such that in order to be successful, teams must be able to self-regulate and manage the necessary tasks for themselves. Some elements of this project management can be seen in the use of the Trello board (Appendix B.6) and the regular group check-ins, but there was also day-to-day evidence in Jane's planning and direction as well.

One of the best early examples of this was Jane considering the skills she would need to be an active member of the group; as the only student not enrolled in A Level Computer Science, she recognised she may have to develop skills the others have already picked up from their coursework. Rather than invest large amounts of time at the start to develop skills she may not need, she planned a learn-as-you-go approach (18.03.16 lns 87-96):

> J: I mean I might have to like learn it a bit more cause just seeing it on a screen you gotta interact with it to be able to understand it better and I've got people in my group who can help as well cause I think one of them definitely knows so much about Computer Science he's a whiz so he will be he can definitely pick up on it super quick just from looking at the board but he'll just teach the rest of the group teach me yea I think yeah … it will take time to get to grips but I will get there
>
> R: Okay so um are you going to be trying to set goals for yourself each week in terms of trying to learn this as well as sort of contributing to the project or are you just kind of going to let it if a need arises then you'll kind of pick up the sort of
>
> J: Yeah if I need to find something then I'll just pick it up then otherwise then the goals yeah

This exchange hints not only at Jane's willingness to stick to an as-needed approach to her programming skills, but again touches on the high value she put on the teamwork aspect of the project. This often played in to her efforts to plan for the project, and on her problem-solving strategies.

Jane sees the delineation of roles based on existing skills to be important to her educational strategy. Because the groups were formed on the basis of a personality test (see footnote in 5.6.1), Jane had some support for her self-defined role, and had a fairly clear vision of what that role would likely be (18.03.20 lns 8-15):

> J: It was just like try I was think like we'd better do like a plan on Wednesday of how we're going to do everything what we need to do like a to-do list and like separate some job roles and think about who would be good for them yeah

R: Okay um and what job role do you see for yourself?

J: Umm I feel like I'll be the like the one who tries to organise and keep everyone like make sure we're on schedule I wouldn't say like team leader but just like the one who makes sure everybody's doing their thing I hope we don't I don't really want there to be a like a proper team leader

I have already touched on the importance of teamwork and meetings for this group; Jane here included both of these elements in her project-management strategy. She was taking the idea of creating an agenda and pairing it with the idea of playing to individual strengths to help the team set reasonable goals for each member. Jane saw herself as fairly organised (in September she suggested that she can be *so* organised it becomes a tool for procrastination), and so she envisioned herself as the individual most likely to be responsible for keeping everyone on track.

As the project moved forward, the addition of the Trello board removed the need for someone to be dedicating time specifically to tracking the team's progress, but the team was still regularly checking in with Jane as the chronicler of the group. Despite doing little to no programming in the early portions of the project, Jane was still quite aware of progress or lack thereof (18.03.29 lns 1-6):

R: Okay so um yesterday I saw the design starting to take full shape out on both the paper and the Power Point um as you were starting to actually manipulate things and actually look at them on the paper, is it working out the way you kind of envisioned?

J: Yeah slightly but it's gonna hopefully at first we weren't yeah we weren't really sure of everything but now we've kinda got the options that we want and how it's gonna look like with those different options… [linking customers to reviews or linking the customers by purchases in common]

While the remainder of the group had been utilising the Trello board as a means of communication and task allocation, Jane had been relying much more on individual observation or direct communication, often not making note of the Trello at all as she worked on the presentation (18.04.20 lns 93-99):

> J: Umm I'd say actually looking at well not by doing the report but actually looking on cause actually I didn't really look on Trello before but then I looked cause I had to look on Trello for the report and everything for the plan I kind of just realised that when we've just figured out how to do the combinations it will be quite easy like that is the main blockage right now that we still haven't managed to pass get through umm has anything that I've realised yeah that like just that the combos is the blockage in the road right now and we need that to proceed with the code

The rationale behind Jane's decision to rely less on the task board was fairly easy to understand; at this point, progress on the board has stagnated, and all that can really be determined from it at that time was that work had temporarily ceased. The face-to-face meetings with her team provided Jane with the cause of the delay and the expected outlook upon a successful resolution. When writing the interim report, Jane found it necessary to use both the Trello and her typical updates to give her an optimistic (and, as it turns out, accurate) view of their prospects once the current issues are resolved.

It may seem that until this point Jane had done very little in terms of managing the project itself; as noted previously, the team meetings and Trello tasks spawned from these meetings have been acting as an accountability aide and so Jane had not had to step up in that capacity. Rather, it is her aspects of the project where Jane has had to manage her time effectively to deliver a product that will help her teammates. Aside from a single week in which Jane attempted to do some coding (more on that later), Jane's entire focus was on writing a coherent report, and on creating an engaging presentation. This being said, when the group tasks were all related to her work, she was willing to once again take charge (18.05.18 lns 113-123):

> J: Well what I've done like I did what I've known and then there's only a couple of things that have to be added in but on that I've made a list at like the front like a title page just before that a list of stuff that needs to be added but like so like the code like screenshots of the final product and stuff like that that I and the some of the options so if Hannah creates more then she can update it on there so people can access that at on One Drive and just look like I can add that in cause I have so Matthew would be the one with

the final product view so screenshot that and add it in and some other stuff so then I've just made a list of stuff that needs to be added that I can't add because I don't have the information on my computer and then they've just got to do it

R: Okay so you're it sounds like you've got a fairly good system for delegating

J: Yeah

Jane was taking the organisation of the final presentation quite seriously, as it is the element of the project that most completely reflected her contributions. This meant asking for contributions from her teammates, including screenshots of their own work. Because Jane had a vision in her head of what would work most effectively, she provided specific guidance on what to include. The end result, as can be seen in Appendix B7 and B5, is a thorough and complete report, and a well thought-out presentation that, as mentioned earlier, Jane believes was critical to her team's success.

6.6. Hannah and Jane's differing views of events within the project

One of the benefits of working with two individuals in the same project group is that this afforded multiple perspectives of certain events in the project timeline. Because the girls came in with different backgrounds and took on different roles within the project, these perspectives are even more distinctive. Hannah's views of programming differed from Jane's even before either fully understood what was being asked of them; while Jane had a respectable theoretical background from her GCSEs, Hannah's theoretical understanding was supported by her experiences not only in her A Levels, but in her independent programming as well. One illustrative example of this is from two separate interviews held on the 9th of March, in which each girl was asked to consider a simile from the Khan Academy tutorial they had been working on:

J.18.03.09 lns 74-87

R: Umm one of the things that was mentioned in that first tutorial video on the Khan Academy website the one that …umm was it talked about giving the computer a series of commands um which is kind of what you touched on already but then the next part said "think of the computer as a very obedient dog, listening to your every command" does that seem like an appropriate metaphor or would you change that somehow?

J: Yeah I mean it's quite easy to understand I guess for people cause you tell it what to do and it does it but yeah and if you didn't tell it the right way it wouldn't do it so if you've got a mistake somewhere it wouldn't actually run any of it but yeah I reckon it's quite it's quite a good one but then obviously dogs can like do their own thing as well but yeah it's good

R: So like if you're if you tell your dog 'we're going for a walk' or if you someone else says 'we're going out' the dog still recognises 'walk' or 'out' and they're like 'oh my goodness' but if you're like if you say that to a computer-

J: It wouldn't yeah

Hh.18.03.09 lns 58-67

R: Okay um and one of the things so I went through and sort of looked at some of the introductory videos that were on the Khan Academy website um just to kind of get an idea of how it was being presented and one of the things that really struck me was a comment that they made about 'think of the computer as a very obedient dog, listening to your every command'

Hh: Yeah

R: Having now a little bit more background than the average person do you think that that's an appropriate metaphor or how would you change that or clarify that?

Hh: Hmmm I'd agree… because as I said it's writing instructions and then it does what you say so it's like an obedient dog to be fair so I I'd agree [laughs]

The above was quite fascinating, as it indicates that Hannah was quite optimistic about her programming; if she codes for something, it will work. Jane was a bit more reserved in her reply; she believed the computer will obey, but only if you've given it the correct commands.

What is interesting is that just prior to the exchange with Hannah, she and I had been discussing what can go wrong, and she had related an anecdote about an error in code when she switched from work in JavaScript to work in C#, and yet the possibility of a bug in the code did not occur to her in terms of the commands she was giving her 'dog'. At this point in the project, Jane was far more unsure of her own programming capabilities than was Hannah, and these conversations, less than an hour apart from each other, provide a prime illustration of this.

Communication between Hannah and Jane was critical throughout the project, as their roles fed into each other; Hannah's experiences with the coding had to make it into Jane's presentation and report, and Jane's oversight and direction helped Hannah to plan what her next steps were. As previously mentioned, Jane worked hard to develop these communication skills, and the team as a whole fostered an environment in which frequent updates and meetings were the norm. This meant that when there were hiccups that perhaps delayed progress, the whole team was aware:

J.18.03.29 lns 76-80

J: Yeah we haven't really started on the programming Hannah Chris sort of last time they just had to they were trying to figure out a way of collab- putting it together the products and the brands but then they realised they were doing it in the wrong JavaScript type thing so it wasn't working [laughing] but they know that so next time they're gonna do that and I think next week will be mainly code not next week but you know the next time we do it

Hh.18.03.29 lns 43-51

Hh: It is a bit yeah cause at first we realised we were putting it in to the wrong JS file cause we we would delete everything but yet the chart was still loading so we were going okay so we don't need this file then so we deleted the file altogether and the chart was still loading so we didn't need it so we were like okay so where is the JS file that is causing the chart to become a chart and it took us like 20 minutes to find then we realised okay we've been doing it on the wrong thing all the time that's why nothing on the chart's been changing anyways we tried what we were doing again and not much would change really um all that I've done so far is we used to have the brand then coming

> off the product then coming off the review then coming off the person doing it I basically got rid of it and just shortened it to just brand-product-review

While Jane's recollection of events lacks the technical language of Hannah's, it reveals that she has either been paying close attention to Hannah's coding, or been briefed in sufficient detail to be able to provide a descriptive summary of events. The greater level of detail in Hannah's recollection is due most likely to her first-hand experience of the situation, as well as her need to understand the problem thoroughly enough to correct it. Jane's account contains less detail, but is informative enough to provide an overview such as might appear in a report.

Another perhaps defining moment in the project is the day that Hannah and Jane essentially swapped roles. Hannah planned to take over editing of the report from Jane, and to add in some of the details that might have escaped her notice. Jane for her part was planning to format the product nodes, colour coding them according to the average number of stars they had from their reviews. They prepare for this in quite different ways, with Jane doing some preliminary research from both the KeyLines website and from the work done by her peers (J.18.04.30 lns 7-11):

> R: Umm how have you sort of prepared for that besides looking at the demos?
>
> J: Umm I don't that was pretty much it just looked at some of the demos I also actually looked at somebody else another person one of my friends anyway in a different group in the Computer Science project was going through his code and showing me some of the stuff he had done so I was just kind of like I kind of like just looked at that as well I yeah

Jane viewed her foray into programming as an opportunity to pick up some computer-related skills, which is not surprising; she came into the project with relatively few, and so had developed a plan for how to successfully complete the task ahead of her. Hannah however seemed to show great self-confidence in her role switching, believing she already had the skills necessary to help improve the report (Hh.18.05.01 lns 5-15):

R: Umm but is there anything that you plan to try to take out of that report whether it's reading through what's already been done or kind of using it as an excuse to plan ahead umm

Hh: Uhhh so I know that tomorrow we're all gonna basically uh at some point during the day just stop everything that we're doing cause we're given as I said given most of the documentation stuff to Jane and most of us don't even know what's in what's written in it and stuff and so we're all just going to stop and kind of get Jane to explain to us what she's done already and if there's anything we can add or improve as a group then it will get it done a lot quicker so hopefully tomorrow we can get most of it done um do as much as we can um and then if she's maybe done a few spelling mistakes we can pick up on it, if she's missed a key bit we can add to it so it's just we're gonna plan and hopefully to do that maybe that period before break cause we only have one period before break so we might just do it then

Hannah did not mention any benefits she expected to gain from the report writing portion, in terms of adding to her general view of the project. She did have several ways in which she believed she will be able to add to the report, however, and it is in these areas that she focussed her attention. Whereas Jane makes the development of transferrable skills a major focus of her work within the project, Hannah views these as secondary behind her programming ambitions. This also plays out in their recaps of the 'swap day', though admittedly the long gap between this day and the subsequent interviews[42] may certainly have had some impact. When Hannah was asked about the report though, her account shows that the whole team had put a lot of collaborative effort into the report on the day (Hh.18.05.15 lns 105-120):

Hh: Uh so yeah we kind of all just dropped the coding um cause Jane was doing most of the report and we didn't know anything that was in it … she couldn't really do the stuff

[42] As noted in the methods section of the methodology, there was a gap in interviews due to unavoidable personal commitments on the part of the researcher

about like the programming side of it the struggles that we had with the programming cause she wasn't really doing that so I kind of took on the role of putting out what we struggled what we managed to achieve I even put some snippets of code that we did in there and then umm we put some screenshots of our development umm in the code and stuff so I kind of focussed on the coding side of the report if that makes sense umm Matthew went through and structured the presentation so kind of made a slide for each part we need to cover … then me Jane mainly just finished it off and we sent it to um can't remember her name one of the mentors yeah and she um checked it all through and gave us loads of points to finish so the week after that we got it back and Jane went through it and kind of marked it and checked it compared to what that woman said to do differently and the rest of us went back to focusing on the code and stuff so yeah that's what we did

Hannah had significantly less to contribute regarding the colour-coding of the combos, which Jane had attempted while the rest of the team was working on the report (H.18.05.15 lns 7-9):

Hh: Umm we have achieved a lot more since obviously the KeyLines people have come in so we've we've got combos sorted now Chris has achieved the colour coding Jane first attempted to do it but she couldn't do it so Chris then did it which he did it really well…

In terms of Hannah's priorities, this account was sufficient: there was an element of the project that needed completion, and a more computer savvy individual took over when a more novice programmer was unable to complete the task. There is no hint of negativity or judgement, but it was not of any great import to Hannah the programmer who completed the feature, so long as it was done.

While Jane recalled more detail of her attempts to code, she too seemed inclined to dismiss her struggles and focus more on the fact that the task was completed and she had contributed in another way (J.18.05.11 lns 26-28…39-42):

J: Well I just well 'if' statements but it just didn't work really and then maybe it might have been something to do with like the order of stuff and everything in the end Chris just did it because then I just worked on the report…I don't know what he did for the halos cause that was just like kind of nearing the end of the day on Wednesday so we didn't really have that much to check everything but next week cause we have to prepare our presentations, we're going over like everyone's going over everything they've done so everyone knows everything everyone else has done so we have an idea

Jane's account here appears to trivialise the amount of effort she put in to getting the colour-coding to work; she not only researched by viewing KeyLines demos and the API reference, she tried several different approaches to the code itself, and did independent research on the subject using an external coding help site before collaborating with her peers. However, in the end, the main point for both girls was that the job was done, and that the group remained on target.

For both girls, and indeed the group as a whole, the hard work of both paid off when their group was named the judge's choice at the presentation day. Besides having a presentation that went on for exactly the allocated time (something all the group members seemed quite proud of), there was always going to be one factor that contributed most significantly to their victory. Each girl had their own opinion on what it was and, unsurprisingly, those opinions differed:

J.18.06.08 lns 7-11:

R: Um what do you think the biggest factor for those judges was in making that decision?

J: Well we marketed it more towards like having people we were selling it for while that's what they told us anyways we had goal and how we had like a client and how we were gonna like make the product for them and not many other groups actually did that

Hh.18.05.24 lns 4-10

R: Umm did they tell what that the factor was that kind of brought you guys over some of the other groups

H: Uh yeah one of the guys did come over to us a said he was impressed that we were the only ones who got combos working which we knew so we tried to kind of stress that when we were doing our presentations cause uh one of the groups came up to us and said 'oh what

which was the whole initial kind of question is selling the intelligence and we sold it

makes yours better than everyone else's or stand out' and we really mentioned like about the whole combos situation and stuff…

While Hannah did go on to mention the fact that they had catered to a particular client, and Jane did eventually mention combos, both felt their own contributions to the team carried the most weight for their team. In the end though, both girls were able to take away a sense of pride over what they had accomplished over the preceding months, and were able to take these experiences with them as they moved on to the next phases of their educational journeys.

CHAPTER 7- A comparison of the three cases

7.1. A comparison of the learners

One of the primary strengths of this research was the diversity of the student volunteers who acted as research participants. This diversity was more the result of accident than design; despite relatively high interest, in the end only three students returned all their forms in a timeframe sufficient to allow for all the necessary pre-Challenge data collection. It was quite fortuitous that the ones that were available represented each of the demographics I might have hoped for under the circumstances: Hannah and Jane were both enrolled in three A Level courses each, while Hamish was pursuing the BTEC Extended Diploma in Applied Science. All three took a Maths course, with Hannah and Jane selecting it as one of their A Levels, and Hamish taking a Core Maths course. Because the UTC had a dedicated STEM focus, all students were required to enrol in either A Level or Core Maths, so there would not have been an option to speak to a student not enrolled in Maths at some level.

For two of the participants, the UTC model was still relatively new; both Hamish and Hannah joined the school only a few months earlier, at the start of the school year in which the research took place. Each of them therefore had experienced three mini-Projects at the start of the year (in Engineering, Physics, and Biology), and one other Challenge Project prior to the ones observed for this thesis. They were therefore not discovering a new project format during my research, but they were still new enough that some general project-related skills were still being developed. This was not unique to the newcomers, however; Jane was not in her first year in the school and had thus previously completed several Challenge Projects, but was still discovering things she had not done previously, such as the writing of a formal report. This was considered by several of the stakeholders[43] to be a major benefit of the Challenge set-up; no two projects are so alike that the students are never merely revisiting the skills and knowledge from a previous project.

In terms of student preference, only Hannah was enrolled in her first choice project, and one that aligned with any of her courses. Jane had indicated a preference for the Water Monitoring project but, due to oversubscription, was moved to the Computer Science project.

[43] Several students expressed this sentiment, as did one of the instructors

Ironically Hamish, who was in the Water Management project, would also not have been there had he been given the choice. He was allocated to the project by his friends, having been absent the day student interest was registered. He confided to me that, given the choice, he likely would have chosen the Engineering project, but was not entirely unhappy with his project selection as it represented a chance to learn something about a topic with which he had little familiarity prior to this. Hannah was quite at the other extreme in this regard; not only was she placed in her first choice project, she also had direct experience with the tools being utilised throughout the project. This did not prevent her from struggling with some aspects of the project as we have seen, but it did mean her challenges were different than those of Hamish and Jane. Hannah's motivations for developing her skills also differed from Hamish and Jane; she intends to pursue a career related to her project, and so this Challenge was a valuable exercise for her in terms of gaining applicable experience for her career.

For Hamish and Jane, career-related projects were slightly harder to come by, as both are considering pursuing careers in the medical field. Jane had at the start of the year planned to go directly into a medical programme[44] after A Levels, but has since developed several backup plans in case she in unable to achieve the necessary marks, typically AAA or A*AA. Hamish intends to pursue a paramedic qualification immediately after BTEC, and may then pursue either advanced paramedic qualifications or medicine. Due to practical considerations, Challenge Projects offering direct experience with patient care and treatment were unlikely, though certainly projects that closely relate occur. An example of this is the project they both completed just prior to the start of the study, which focussed on bacterial transformation through the insertion of the pGLO plasmid. This project taught them several laboratory techniques that they felt might prove useful in their future training or studies. In general, though, the students at the UTC have developed a number of ways to make each project meaningful and impactful for themselves regardless of discipline, and in the case of the Computer Science and Water Management projects, they did this by differentiating their roles to suit their strengths and interests (§8.3 discusses potential implications of this).

[44] In the UK, it is possible to be admitted into a direct entry Medicine programme, rather than applying to a pre-medicine course and then applying separately to a clinical programme. However, it is possible in the UK to move to medicine after the completion of another degree, as a graduate entry medical course

It is I suspect natural that, given the very different backgrounds, interests, and ambitions of the three participants, they would have taken on very different roles within their projects. With Hannah and Jane in the same group, it would have been difficult for them to take on the same roles regardless of interest, but as it turns out, having very different personal aims for the project was an advantage to their team. In Hannah and Jane's group, it meant that rarely did anyone have to split the focus from their assigned tasks because they had faith that their teammates were capable of handling the other elements of the project. Hamish's project structure did not allow for quite the same sort of differentiation on most days, but when the opportunity arose, such as on the day the primary school students came to visit, he was ready and willing to take on an active planning role within his group, as he found teaching quite natural.

7.2. Differing natures of the projects

Considering the second research question is focussed primarily on how the different elements of the project impact the learning, it is worth here comparing the structure of the two projects, before then focusing on what impact these structures had. In this section, I will first focus on the aims of the two projects, which were laid out in quite different ways. I will then consider how the structure of the projects was designed to meet those aims, and how effectively it did so. This I hope will provide a suitable backdrop for relating the different learning outcomes each student experienced.

The differences between the projects became evident as soon as the project syllabi (Appendix A.1 and A.6) were available. The Water Management project is laid out in terms of project outcomes, and learning and teaching objectives. The former laid out the three target outcomes: "produce a management plan for a local river", "make a catchment conceptualisation map", and "deliver an event for primary school students based upon water management". These are followed by a series of learning objectives that are primarily factual/conceptual/foundational (Anderson et al., 2001; Fink, 2013) and a series of teaching objectives that are primarily procedural/application (Anderson et al., 2001; Fink, 2013) in nature. This is then followed by a breakdown of the weeks of the Challenge, with broad categories such as "Analyse weather pattern data and conservation" or "abiotic factors".

The Computer Science project brief likewise suggests an outcome-students analyse data to identify themes which can then be used to do one of two things: sell the intelligence (to

investor or customers) or sell the solution (to a problem found through the analysis). There is also a section titled "things to consider" that includes prompting questions related not only to the technical skills, but also to the underlying philosophy of such a project. This project too comes with a timetable, though it is more of a schedule of deadlines than a list of topics to be covered. The difference may come down to the source of the briefs; in the case of the Water Management project, an instructor from the UTC was the primary course designer. In the case of the Computer Science project, two external employers worked to design a project within the Industrial Cadets framework.

The differences present in the structure of the project briefs were largely mirrored in the structure of the courses themselves. The Water Management project featured individual sessions aimed at allowing students to meet each of the learning objectives, e.g., the learning objective "Learn a range of biotic and abiotic sampling and analysis techniques" was designed to be met through the activities on the 28th of March and the 18th of April (Easter holidays were responsible for the break between these dates). The dates designated for biotic and then abiotic sampling were swapped due to personnel availability, but the lesson structure and outcomes remained the same. Because each student was responsible for completing each of the activities, there was relatively little flexibility in what tasks the students accomplished and when. On the 21st of March, the weather data tables were all compiled during the time dedicated to compiling, for example. Except for the final session where the students were planning and running activities for the primary school children, they had relatively little direct input into the tasks for each day, with the majority of time structured for either direct instruction or developing prescribed skills.

The Computer Science project was much less structured in terms of what was being accomplished on which date. While specific dates were set by which students needed to submit interim and final reports, it was left to each group to determine how long each individual task would take them. From the project brief, it might appear as if the expectation had been for students to spend several weeks planning and a single week coding, but input from industry mentors meant that few students stuck to this suggestion. It was indeed merely a suggestion, as both the mentors and the instructor encouraged the students to adapt the project to their needs. For Hannah and Jane's team, this meant creating the presentation and the product simultaneously, as there were enough people to have group members dedicated to each role. It was also more difficult to prescribe a certain number of sessions to each element of the final

project as the end product in the CS project was in many ways more open-ended than the Water Management project.

The CS project did have some limitations that the Water Management project did not, however, primarily in terms of practical limitations based on the software the students had access to. Aside from the difficulty of teaching still relatively novice programmers a new language and expecting them to be able to successfully implement it in a completely new sort of program, students also found that they had little idea how to check their work and make corrections in this new language. As Hannah put it, "it's just silly stuff like that that anyone could really miss kind of thing if you don't do this as an actual job" (H.18.05.15 lns 159-160). This was also true of being able to manipulate the program to present the data in alternate formats. While there were plenty of options regarding how to present the networks, students *had* to make a choice from that list, as developing new features was well beyond their abilities. The company that produced the software spent months developing and testing the combos feature that Hannah was so proud of mastering, for example. While the CS students had fewer restrictions on their time than the Water Management students did, there were restrictions on them nonetheless.

7.3. The development of skills across the cases

While there were of course limits to what the students could accomplish within their projects, whether these limits were imposed upon them by the instructors/mentors or by the available resources, all the students were given the opportunity to develop different skills[45] throughout their projects. Some of these skills were evident in all three cases, and some were unique to the project and to the role of the individual. In keeping with the constructivist philosophy that has informed this work, it also must be acknowledged that the skills that each student accessed, developed, or augmented during their projects were all to some extent influenced by their prior experiences. A student who knows that a particular strategy has proved useful in the past is going to be more likely to use this strategy again. This does not indicate that

[45] Fink (2013) uses skills to refer to a particular type of application of knowledge. While these skills constitute some of what is meant here, the term is being used in a broader sense, to include most of his Application category, as well as elements of Integration and Learning how to learn. In terms of Anderson et al. (2001), skills in this case most closely ties to the procedural knowledge dimension, though evaluation and creation across his knowledge dimensions may also qualify

no learning has taken place; in this case, the evidence of learning would be in the decision to transfer the skill or strategy from one context to another, or to find ways of more efficiently implementing these strategies.

If we look first at the *types* of skills necessary for each project, it is clear that the structure of the project can have an influence on these. The CS project relied much more on the learners being able to self-regulate, plan, and communicate within their teams regarding their goals. Both Hannah and Jane had to consider how long each task would take them, and plan accordingly. When they encountered difficulties, they had support from the instructor and the mentors, but the ultimate responsibility for staying on task fell to them. They also had to explore their creativity to a greater extent, as despite a finite number of design elements being available to them, there were a near infinite number of combinations of these elements, and multiple possible focal points from the data. Choosing combos over hierarchy charts or individual nodes, and choosing to put brands rather than people as the combos are just two examples of the creative decisions the team had to make.

Hamish in contrast had far fewer creative or practical decisions to make throughout his project. Each Challenge day had specific objectives, such as the biotic factor day: students first learned how to perform the kick sampling technique, and then went into the field to collect their samples. They then came back and classified and quantified the aquatic organisms in their samples, and used a number of charts (see Appendix A.9 for one example) to estimate general water quality on the basis of the wildlife present. Hamish left early and so was not present for the analysis and interpretation portion, but he did recreate the activity on a smaller scale during our interviews. While he did have to access multiple skills relating to reasoning and analysis, his work involved relatively little creativity, when compared to the CS project. The one element where some creativity was required was in preparations for the Primary day, where Hamish was encouraged to plan the details of his flow deflectors activity. Both the observations and the interview reveal this was the day he approached with the greatest enthusiasm.

It may appear as if the projects' differences might mean that there was no skill development in common as they progressed. However, several transferrable skills were exhibited in all three cases, even if those skills did manifest differently in each one. Perhaps the most critical of these was planning. Jane showed perhaps the most straightforward example of this, as her team organiser. Because of her group's dynamic, she did share this responsibility

with Hannah and the rest of the team, using aides such as a whiteboard and later the Trello to make sure each task was allocated and then completed. Jane had then individual planning to consider, relating specifically to her own tasks. She had to pace her work on the report and the presentation so that she was keeping up with the latest developments, but not allow work to pile up, which would result in an unreasonable task list at the end. Hannah had to not only set a plan for her coding based on her prior knowledge of the KeyLines code, but she then had to make several amendments to the plan based on difficulties that arose throughout the project. Hamish had few setbacks of the sort seen in the CS project, but because he had several Challenge days where he had to leave early for various reasons, he had to plan in terms of getting himself caught up. In certain weeks, this meant being caught up at the start of the Challenge session via a quick conversation with his teammates; some weeks were more involved and required detailed communication with his partners to ensure he was able to re-join the group prepared for the tasks ahead.

This communication was also a central theme across all three cases; while it meant different things to each of the participants, being able to effectively communicate was crucial to the successful completion of the project. Hamish's team completed the same tasks as one another each week, so his communication centred primarily around the team's need to ensure there was agreement regarding their outcomes for their report (Appendix B.7). More important perhaps to Hamish was considering how best his team could communicate their findings to the general public for the purposes of managing and maintaining local water sources. A key example was his opinion on the labelling of certain farm products, such as slug pellets and the impact they could have on local aquatic invertebrates (H.18.03.16 lns 285-287):

> Hs: I'd say that's a very important thing if we start adapting the language that we use to inform consumers about these or even informing them to begin with you'd see a maybe not a dramatic but at least a gradual increase in um appreciation

For Hamish, communication and persuasion of the public was a common theme, a panacea for the problems faced by the Nine Wells ecosystem. He felt that if the message of water conservation could be effectively spread, the public would rally behind the cause.

For Hannah and Jane, communication with a hypothetical audience was also critical, but for quite a different reason. Hannah and Jane were selling a product of their own creation, and this required the development of a new style of communication. While their aim was similarly to persuade their audiences to a particular course of action, they did not have an ethical platform from which to approach this. Rather, their goal was to persuade the audience that their product was superior to those of their peers, and this was primarily through the report and the presentation. The presentation (Appendix B.5) focuses on a clear message: the product created by this team is far easier to use and more appealing than looking at raw data, and by using the product, the client's productivity will be improved. Jane makes use of statistics, 'before and after photos'[46], and other graphics to sell her team's product to the audience. The report and the Power Point itself were a reflection of Jane's understanding of the product, and therefore her attempt to sell it from her perspective, and it was most upon Hannah and Chris to bring the technical elements in verbally on the presentation day (J.18.05.18 lns 99-106):

> J:…it's more about the marketing and selling of the product the presentation is that's how I've done it it's still quite a lot it's still got like why we chose like these options and stuff like how are they useful how are these options useful to the user and like that
>
> R: Okay uh how much technical language had to go into these two things the report and the presentation?
>
> J: The report not a lot the presentation not a lot's in the presentation though it's going to be spoken technical there will be quite a lot of spoken technical language in the presentation

Hannah shared a vision for the final presentation similar to Jane's, and was quite happy to bring in her technical perspective, along with Matthew and Chris. Where Jane's role was to be persuasive, Hannah's was to be precise and accurate, to ensure the client's confidence in her ability to design and build a quality working product.

[46] The primary 'before' photo in the Appendix is actually a video in the original presentation; naturally this does not translate well to the print format, and as the video itself adds no additional information to this study, it is not included as a supplement

As mentioned before, both Hannah and Jane felt that their primary contributions were the ultimate reason for their group's success. This is not because they felt the other did not contribute significantly to the group, but because they were able to construct their own meaning from the project. From Hannah's perspective, the project taught her the value of pursuing challenging and complex programming tasks, and how to cope with debugging the code more effectively. For Jane, the project was about effective marketing and planning with an audience in mind. In Hamish's project, he thought beyond the maintenance of the Nine Wells ecosystem to consider why they were working to maintain it, and so for him his project came to be about protecting local biodiversity. Despite a much more structured schedule of topics, the project was designed in such a manner as to allow him to explore this, and thereby assign personal meaning to the project.

7.4. Lessons from the UTC model

At this point, the primary focus of this thesis has been on the learners and their experiences. The structure of the Challenge projects, or their situation within the larger school context, has been largely peripheral to the discussion. This makes sense in terms of the focus of my research, but it is impossible to separate the learning from the context entirely. Indeed, the second research question ("what effects do different aspects of project learning have on the learning taking place?") specifically focusses on the impact instruction has on learning, and certainly the Challenge model as a whole plays into this. Therefore, this next section will focus on the lessons to be learned from the UTC model as a whole, and in particular the benefits associated with this particular UTC's model for the Challenge project.

As mentioned previously (§1.8), the UTC concept was developed in an attempt to prepare school leavers for the world of work, and to help students build the skills necessary for university, apprenticeships, and jobs. Part of this preparation is the length of the school day: most UTC's run a schedule similar to a full-time job, from 8:30 to 4:30, or similar. Cambridge Academy for Science and Technology (CAST) runs on this schedule, and unlike many nearby sixth forms, it does not allow students to be absent from the site when not in timetabled lessons. While some students such as Hamish bemoaned such restrictions, others felt it allowed them time to collaborate on work or ask for advice from their instructors. Indeed, Hamish too

appreciated having access to his instructors outside of class time, and Jane and Hannah frequently made use of their on-site revision periods to catch up on Challenge work.

Another benefit of the CAST setup is that the Challenge projects last for an entire school day. While the 7 to 8-hour school day is fairly standard across UTC's, the full-day Challenge is unique to CAST. Other UTC's offer projects as well, but the exact format of these is determined by the school, and so time allocation can vary anywhere from two periods per week (McCrone et al., 2019) to entire days. The CAST students appreciated the longer period of dedicated time for their projects, as a means of experiencing something a bit different from the experiences they had in their previous schools (J.18.06.08 lns 443-449):

> R:…how do you feel about the Challenge Projects in general?
>
> J: I like them it just expands your learning and your experience as well and in Year 12 they're actually fun like cause you get to choose and even though I didn't really kind of get to choose Computer Science it was still a fun project to do and I did learn a lot from it cause yeah and other schools don't really have that and you're stuck doing lessons for like five days a week and it's nice kind of fun just having that day just to focus on one thing
>
> R: Okay yeah
>
> J: And you don't really have to worry lessons or anything

For Jane, who felt that Challenge is "kind of greater than lessons" (18.06.08 ln 462), these projects offered an opportunity to unwind from the stress of her day-to-day coursework, and while some overlap might prove useful, she did not mind having an experience that was separate and unique. Hamish likewise enjoyed a bit of overlap, but was enthused by the idea of learning something completely new, as happened to him with the Water Management project.

One area where Hamish was less satisfied was the number of projects per year. While he did enjoy the break from his regular schedule and the chance to learn something new, he at the same time did feel the loss of revision time (Hs.18.04.27 lns 16-22):

> Hs:…to be honest a lot of students A Level and BTEC alike we have so much work at the moment that a lot of us would rather just spend Wednesdays doing our own work and so what I think a better system would be if they were to well if I were to change it be like 'it's not compulsory to do every single one, it's compulsory to do maybe a few throughout the year but not every single one' and so if you do get into a spot one term where um the work is just piling up and you have to option to not do a Challenge and catch up on work instead

This quote came from a point where Hamish had fallen behind on his coursework, which may have coloured his opinion, but it was not the only time he hinted for additional flexibility and autonomy. He did not disapprove of the opportunity to expand his learning outside his BTEC coursework, but did not want it to come at the cost of his revision. Neither Hannah nor Jane expressed such an opinion, though the demands on their time as A Level students varied somewhat from Hamish's. Regardless of any objections regarding time allocation, by the end of the project, all participants reported positive feelings towards their experiences with their projects, and felt that it had been a good investment of their time.

Aside from the allocation of time for the projects, there is one other unique feature of the Challenge project: the involvement and input of local employers from local STEM-based industries. This is not unique to CAST, but is one of the defining features of the UTC model as a whole (McCrone et al., 2019). Not every project is *run* by a local employer, but most projects feature significant input from local industry. This may look like the Computer Science project, where local companies ran a specific scheme and came in weekly to assist, or it may look more like the Water Management project, where input from local experts was supplementary and intermittent. In order to understand more what this dynamic looked like, I sat in on the strategy meeting for a third project[47], which was held between the Challenge coordinator, primary instructors, and the appointed liaison from a local engineering firm. The focus of this meeting was very firmly on creating a realistic level of flexibility within each project to allow students to choose roles they were comfortable with. The engineering firm was as dedicated to creating a

[47] This project is not featured elsewhere as none of the students in this project were available until well after the project had begun, and therefore no baseline data could be collected. One participant, pseudonym Hart, did have a number of opinions regarding Challenge in general which will be seen in the Conclusion

project where all students had a chance to contribute in different ways, as it closely mirrored the way a project team in industry would be structured.

It cannot be assumed that this same sort of meeting took place before the start of all the projects, but it is reasonable to assume that some consideration of the connection to industry formed part of the planning process for the Computer Science and Water Management projects as well. Informal conversations with the instructors who coordinated those projects confirmed this, with the CS instructor in particular looking ahead to the long-term implications of the project. He was a strong advocate of project-based learning in general, and was particularly invested in this project because it integrated several elements of the A Level curriculum with the skills and experiences authentic to industry. While the Water Management project had a wider focus and therefore less connection to any one career pathway, the instructor there likewise valued the input of members of local organisations and industry to add authenticity and variety to the project.

CHAPTER 8- Final thoughts and conclusion

8.1. Relation to the first research question

In order to address whether or not the data was sufficient to address the research questions, it is necessary to first revisit them. In this section, I am relating the data to the first question: *how does learning occur during a project-based learning unit in secondary science*? In the literature review, I attempted to sort through a number of different perspectives to define both learning and project-based learning (PBL). Without going into unnecessary repetition of the majority of the literature review, it is worth recalling that learning was defined as *the creation of the potential for a relatively permanent behaviour as a result of reinforced practice or experience,* based on the psychological perspective, and then the practitioner perspective was provided to help classify the learning. While much of the language in this thesis is based off of Fink's (2013) taxonomy, both Anderson (2001) and Fink's taxonomies were used together to identify and classify learning. This is not to say there were not instances in which one was more beneficial than the other, but the use of both in the context of my accepted definition of learning provided a clearer picture of each participant's learning.

As mentioned previously, Anderson et al.'s (2001) taxonomy was particularly useful for classifying learning *objectives*, due to its methodical structure. Fink's (2013) taxonomy is organised to be more useful in observing what learning is taking place, particularly in project-based learning where learning from several taxa may be happening simultaneously. Where the interaction between taxa was a novel occurrence, this could be considered learning, based on Fink's (2013) taxonomy, particularly given his emphasis on the interactive nature of learning (Figure 4.1). Where the participants showed evidence of application where previously they had been displaying understanding (Anderson el al., 2001), this could be classified as a change and was thus also considered learning. Rather than try to identify changes as they occurred, detailed records were kept of any notable[48] behaviours that were observed, either during the lessons or through the interviews, was noted and then considered a potential evidence of learning.

[48] This is certainly a subjective term. Please refer back to sections 2.6.1 and 2.6.2 for more on the observation and interview processes

One particular point to consider is whether all observed behaviours are indeed evidence of learning. It is entirely possible, probable in fact, that the students engaged in behaviours they already had learned prior to the project. This recalls the belief held by Prince and Felder (2006) that project-based learning is primarily about the application of prior knowledge, rather than the acquisition of knew knowledge. While it has been accepted within this thesis that in many instances the application of prior knowledge can constitute learning depending on context, it did add a layer of complexity to the observation and analysis. Hannah provides an excellent example of this. She demonstrated throughout the project a number of programming skills that would certainly be considered quite advanced from the standpoint of Bloom's (1956) or Anderson et al.'s (2001) taxonomy, with the evaluation and eventual synthesis of code. However, this would not necessarily represent learning for the purposes of this thesis, as by her own admission she had worked with this particular API previously. The circumstances were quite different however, and so certainly while Hannah did access and apply prior knowledge, she was becoming more efficient in her use of the code, and developing new skills within the project, and so there is still evidence of change, which in turn provides evidence of learning, based on the accepted definition.

The cases of Hamish and Jane were slightly more clear-cut, as both were in projects well outside their areas of expertise. Both explicitly mentioned elements that were new to them: Hamish had done little work with ecology before this Challenge, and Jane had never written a formal report. For this reason, it was easier to assume that Hamish's awareness of water management strategies and the rationale behind them were new, as was his concern about biodiversity. Jane was learning how to write and structure a report from the mentors as she went, but relying heavily on the teamwork and communication skills she had previously, likely from other Challenge projects. The pre-project interviews were critical in helping to sort application from acquisition in these cases, as in Hannah's. The problem came in deciding under which circumstances application might still be evidence of learning, as this presented one of the greyest areas of the project.

One strategy that was considered was adding another layer of coding, wherein after the knowledge or skill had been identified and classified according to taxonomic category, it would then be classified as either 'new' or 'prior'. This became problematic due to the fact that what was most commonly occurring was that the participants were indeed showing evidence of prior

knowledge or skills, but in contexts they had not previously experienced. Again, Hannah is a prime example of this; she had to reference her previous experiences in order to determine a strategy that would work for her when the project was not going according to plan, and it was necessary for her to evaluate those strategies and make changes. This was one area where Anderson et al.'s (2001) taxonomy was particularly useful; they looked not only at the *types* of knowledge students might exhibit but also the degree to which they exhibit them. It was therefore possible to watch Hannah try to apply a programming skill, analyse her code when issues emerged, evaluate her options, and then create an alternative plan. It is these changes in this particular context that I classified as learning, rather than the skill of selecting and importing a particular bit of code.

8.1.1. Hamish

Having considered what I classify as learning, it is now my intent to provide specific examples of this from each of the three cases presented above. As much of the evidence has already been presented in the individual cases, the emphasis here is more on explaining how each student's narrative provides evidence of this learning, from the point of view of the research question above. Returning to Hamish, this seems initially to be an easy task. The most notable example of Hamish's learning relates to the development of his conception of biodiversity, and its increasingly central role in his thinking. However, Hamish did not just display and articulate (Reif, 1985) an increasingly complex conceptual knowledge related to biodiversity (Appendix B.3); he also showed increasing engagement with the project, and took his growing understanding of biodiversity and connected it to the community and its needs. Initially, Hamish is focussed on human needs and how these are impacted by the relative health of the ecosystem, which may include biodiversity. Biodiversity was not initially a primary focus of his, and was merely one of the many factors he considers at the start of the Challenge project (§3.4.1).

The shift in Hamish's focus, from how the environment can affect humans to how humans can affect the environment, represents changes within the caring and human dimensions of Fink's (2013) taxonomy. This change was not linear; as was seen throughout chapters three and four, Hamish's focus tended to shift with the sessions he had recently been part of. This

made it difficult to classify some instances as learning, based on the idea that my accepted definition includes the notion that these changes be *relatively permanent*. This of course does allow for some flexibility, as what counts as relatively permanent is not defined here; while changes that are the result of temporary states such as inebriation[49] or fatigue would not count, it is harder to say with certainty that Hamish's passing feelings immediately after a lesson did not have a cumulative effect on his attitudes towards biodiversity.

The most obvious solution that presented itself was to look specifically at Hamish's final interview, conducted three weeks after the conclusion of the project. Certainly, three weeks after the project's conclusion is not enough to determine *permanent* changes, but might reasonably be seen as *relatively* permanent, when compared to Hamish's temporary enthusiasm immediately after a lesson. Hamish's views still contained certain elements that had appeared early on (such as light and noise pollution), but his negative opinion of urban structures remained tempered with his belief that some such developments might be necessary (18.06.11 lns 105-123):

> R: Okay alright and then in specific in particular with the Nine Wells ecosystem what factors do you think uh the Nine Wells ecosystem faces that could increase or decrease biodiversity there what could we do to what are we doing that could harm it, what are we doing that we could help
>
> Hs: Okay yeah so one thing I didn't mention was urban structures which again really depends on the type cause you can get urban structures which will increase the um environmental features of a place so like um oh what the heck were they called did the whole activity based on them flow deflectors and so so you can get structures like that which will increase it and also specifically at the Nine Wells place you had uh farm land on a hill that was just beyond the Nine Wells thing and they were finding that surface runoff from excess rain would then include pesticides that we used in those fields were taken in to the Nine Wells site and they've um dug a ditch and they've inserted drains so that it will stop these pesticides from reaching the Nine Wells so yeah urban structures is a big one in Nine Wells um a positive and a negative cause if you look at the uh ever increasing surrounding urban medical uh medical campus environment around it that is

[49] No evidence suggests that this was ever a factor in any of the cases; it is merely mentioned as Watson (1931) considered changes due to inebriation to not count as learning

> having a negative impact you're increasing the pollution uh I mean uh light pollution, noise pollution, etc. etc. as well as just shortening the amount of um or decreasing the amount of land available um and then you also have all these the flight path of planes and stuff above again the excess noise again yeah but then we have also I say we they have also uh added these urban structures to combat certain issues…

Light and noise pollution had been part of Hamish's conception of pollution before he experienced the site itself (18.03.12), and had not come up during introductory lectures, so that concern cannot be attributed to this project. The belief in human intervention to mitigate the effects of pollution, however, was something that emerged later; in the same interview in which Hamish brought up concerns about noise and light pollution, he initially expressed a lack of familiarity with the concept of a buffer zone to prevent "all of this natural debris … just going straight into the environment and damaging it in that sense, polluting it" (18.03.12 lns 110-111). Prompting was enough to elicit this guess as to the purpose of a buffer zone (or other manmade solution), but it had not been at the forefront of his mind; by June, it was a major theme.

I had my own suspicions at this point regarding the changes to Hamish's conception of biodiversity as well as his emotional investment in maintaining it, but before I began to analyse the data in earnest, I was quite curious to hear his opinion regarding when he felt he had learned the most (18.06.11 lns 152-160, emphasis added):

> R: Okay um and were there any particular elements of this project that you think really made you stop and reconsider that and start to make that change
>
> Hs: Hmm umm I think it was a slow process throughout the whole project I don't think there was one eureka moment where I stopped and though 'hang on this is what ah I've been thinking about this all wrong' um because to be honest it was very much at the back of my mind the only real reason I've been thinking about it is because of your questions [§2.6] about it so some credits to you there um but **I think it's been a slow process throughout the whole thing and as I've slowly gained knowledge throughout the process doing various activities I've been able to build up this sort of description** that I'm now giving of it

This mirrored my own thoughts along these lines; though some days had more dramatic immediate impacts, often by the following session, Hamish had abandoned certain elements of the lessons in favour of newer ideas. They may have held long enough to be *relatively permanent* but were for the most part subsumed into Hamish's larger, growing awareness of biodiversity and its importance.

Hamish on several occasions came in for interviews after sessions and could not recall the particular details of that session. A prime example is his recollection of his visit to Anglian Water (18.06.11 lns 272-278):

> Hs:…when we visited uh Anglian Water and we saw all the processes I can't remember them but there there were processes in which they analysed the water and they were able to deduct how clean it was um and then to an extent make changes to it they didn't they didn't make [inaudible] it was more about monitoring than it was about making changes um but I suppose they could make they could make subtle changes to the water to then make it um safe for us to then uh consume later on in terms of how it's then used in the environment I don't actually know I don't know…

Hamish had been no more specific in our first interview after the trip (18.05.11), or indeed when I spoke to him on his return from the visit on the day. He seemed to be content to know that a number of tests were conducted at the facility, that these tests were necessary, and that the cleanliness of the water was important. This particular day was of interest to me because it actually represented a departure from Hamish's focus on biodiversity; the focus of the facility had been on testing and decontaminating water for human consumption, and his immediate responses focussed on that angle.

By the time we spoke about it in June, Hamish recalled only that the tests were used to monitor water quality, and that this was an important thing to do. Hamish's focus on the needs to the local human population did not carry through, though the use of various testing facilities did. He had with all likelihood allowed this experience and the knowledge he considered most critical to be subsumed under the broad topic of biodiversity and what impacts it, but abandoned any explicit consideration of the elements regarding human consumption. To suggest that Hamish did not 'learn' about the importance of testing water for human consumption would be to open

myself up to charges of hypocrisy; that he recalled those details a week and a half[50] after the visit suggests the shift in his knowledge was at least *relatively* permanent and therefore meets my criteria for learning.

What most likely occurred in this instance is that Hamish did indeed learn about the necessity and mechanism of water testing and treatment, but that he integrated into his existing knowledge structure the elements he felt were necessary. This brings to mind Özdemir and Clark (2007)'s knowledge-as-elements perspective, which suggests that the student's knowledge is built of independent elements that are integrated together to form more complex knowledge structures. In each lesson, Hamish picked up different elements, and by the end had assembled from the pieces a fairly complex image of the factors that influenced biodiversity (18.05.14 lns 394-396):

> Hs:…consumption, development, competition yeah they are very prevalent in what we're talking about but I think if I had to pick one main one for what we're doing we've all been looking this whole topic about how these different things cause a change in the biodiversity…

This is not the first time this quote has appeared in this work, but it is such a critical moment it is worth revisiting. Hamish not only identified for himself the major theme of the project (biodiversity) but he recognised how the individual sessions were introducing him to the different elements that factor into biodiversity, building his knowledge as he went to allow for a more complete picture to form at the end. The specific lesson elements that allowed this to be possible will be considered later on in this chapter.

8.1.2. Hannah

Hannah's case presented challenges that were not present in Hamish's, namely that she was not learning a new subject from a near-zero baseline, and so it was less apparent what was

[50] The visit to Anglian Water took place on the 2nd of May. An immediate follow-up interview was prevented due to my need to travel to America on family business, as discussed in §2.9

new and what was prior knowledge. While Hamish had clearly had some exposure to ecology at the GCSE level, he had not pursued the subject, and it did not form any part of his plans for his future studies. This is not so of Hannah, who has every intention of making Computer Science her career in some capacity, and was engaging in self-study long before she started her A Level coursework. Perhaps more importantly, Hannah had recently completed a week of work experience with the company who had created the SDK*, and so she had an advantage even over her peers. Still, she felt there was a goal for this project (18.03.01 lns 22-23): "so we're basically helping them with their software, they're giving us their SDK and we're just looking at that developing JavaScript skills and basically just a programming sort of thing".

What is perhaps most important from the quote above is that Hannah has already determined the educational objective for the project, even before the official launch (which offers her the specific task through which they will be meeting those objectives). Regardless of the exact structure of the project, Hannah intends to develop her JavaScript skills. At this point, it was not possible to say whether this development would mean learning new skills, or merely expanding the functionality of her current ones. Both would have represented changes to her existing skills, and thus would both represent learning. The issue for me as a researcher then was to understand what skills Hannah had possessed before the project, so as to be able to recognise learning when it took place.

Hannah's early impression of her own competence with the KeyLines SDK is quite positive, with her almost relishing stepping into a leadership role to show off what she is capable of (18.03.09 lns 154-157):

> Hh: … I'm hoping that next week Cambridge Intelligence come along and they'll explain their SDK cause I'll be like [snaps] got it but everyone else cause a lot of people are coming up asking me 'what do they do' cause they didn't know the company and stuff so I've kind of made a lot of people aware of what the company actually do and what their software's like and stuff

If I accept that Hannah's self-assessment is accurate here, she already has a fairly advanced understanding of KeyLines, and enough JavaScript knowledge to be able to successfully

program within the SDK. Early on, she also feels as if there will be some transfer from this project to her A Level coursework, specifically concerning big data (18.03.20 lns 4-7):

> Hh: Yeah kind of like me and [instructor] were talking about it and he said it seems really easy and we should all get grasps of it quite quickly um because in our A Levels we have to look at big data* which is basically what we're doing now and so he said it would be really helpful for us to look into it

What is interesting here is that, according to her instructor later in the project, the data the students are using here does not constitute big data. This topic ceases to be a priority for Hannah in the face of the procedural issues that followed, and thus there was no direct follow up on this, so whether her views of big data changed through this project or not is uncertain.

Where there is more evidence of change is in regard to her comfort with the KeyLines code, and with her own process for solving problems. By Hannah's own account, her prior experience with KeyLines involved selecting the source code for the features she wanted from the demos* (Appendix A.10), and with far less data 18.03.29 lns 12-14):

> Hh: I was only working with a small amount of data so when I was coding them to do things I would just hard code it or instead of finding common links I just wrote all the separate nodes I wanted within a combo

Because of this, there were several relevant skills Hannah had not previously had to develop. These mostly related to determining how best to read and group the data in such a way that it was usable in the combos feature. By her own admission, this was a new skill for her, and her thoughts across several interview sessions reveals how her understanding of the problem and its possible solutions developed:

18.03.22 lns 88-89	I'm not sure if there's a way you can tell the computer to find the same number if you know what I mean

18.03.29 lns 16-18 H: Um and now with this it's a lot different you have to somehow write um a line of code that will reference to all of the bits of data that have something similar within them and then pull it out instead of writing each separate one like I did

18.04.17 lns 61-63 it's just finding the syntax to call similar property they all have and it does the computer does that itself

18.04.24 lns 6-8 H: Uhhh well we were trying to combine nodes and we knew the syntax for the code we just didn't know how to reference to the data umm because what had happened was when we had taken and downloaded the data from the site that they provided us with umm they then gave us this thing called like parse parser script or whatever which um would change that data format to a more KeyLines friendly way cause KeyLine couldn't read that formatted way to be able to interpret it and visualise it but we can't see the output of that we only see basically the raw data

18.04.26 lns 3-13 H: Uhhh so our biggest problem that we wanted to deal with was be able to know how to grab the data we want to be able to do something with it and the thing we wanted to do was combos um so they helped us through the email that one of their other um colleagues sent us through the iteration the loop to go through all of the data take out which ones are reviews and put them in an object

R: Okay

H: And in that object it had a list of all of the different sorts of ASIN IDs and next to that there'd be an array that would contain all of the reviews that had reviewed on that product uh so we got that sorted which is organised and everything separated them based on the

> product that they've commented on so from that we could literally just reference the array put it in and create the combo

Regardless of what else was going on in the project, Hannah never lost her determination to successfully build combos with the data, as evidence that she could handle the newest and most complicated feature offered. Because she had never dealt with such large quantities of data before, she had never had to deal with determining how to reference from a database, and the added complication of using a parser and being unfamiliar with the output added much confusion to an already unfamiliar task.

Hannah's word choice as she considers this problem across several sessions is revealing. In the first instance, she was referring not to her own data, but to the raw Star Wars scene data that I provided as part of a brainstorming activity on the 22nd of March. It is relevant, however, as the task was similar in nature to that which would eventually be required for the project-writing a line of code that would instruct the computer to run through the data and extract all entries that shared a similar property. Her language is not technical, and her ideas are not yet fully formed. As she reads through the API* reference for KeyLines, views demos, and searches additional websites for help, her word choice becomes more technical, and the process she describes becomes increasingly detailed. While this all essentially represents her thinking about one single skill, it is the one that proved essential for the success of the entire project.

Equally important to Hannah's success was her ability to act as a self-directed learner. This ability was harder to classify as learning, as there was less obviously linear growth in this area, with Hannah's strategies for managing her learning depending on the context. What Anderson et al. (2001) calls metacognitive knowledge and Fink (2013) calls learning how to learn played a critical role in the development of Hannah's programming knowledge above. There is no way to know how many of the strategies Hannah employed were ones she already knew, but being able to adapt those strategies to fit novel situations may be seen as evidence that Hannah is learning from her surroundings. As mentioned in the literature review, one of the benefits of project-based learning is that it does provide a more authentic context for learning, and this learning may be to use old skills in new ways.

Hannah's early strategies, of delegating tasks based on ability and setting out an agenda, cannot be attributed to the project with any degree of certainty, though certainly the team as a whole did adapt a new strategy for splitting up individual tasks after feedback from the mentors. It is the methods Hannah used to resolve her issues with the programming that can most reliably considered changes based on the project itself. Because Hannah had previously been able to hard code all of her data, she had not had to utilise so many resources in completing her work experience project, but for this Challenge, the team as a whole had to think critically about each stage of the project.

Before any of the major issues emerged, Hannah and the team made the determination that they needed to limit the amount of data they start with. This was not so as to be able to hard code the data points, but for an even more basic practical reason: none of their laptops could handle more data. Hannah felt this was perhaps a blessing in disguise, as it allowed the team a chance to test out some features without being slowed down by too much data Hh: "Uh we're gonna kind of work with what we've got currently um and then try and then once we understand KeyLines more bring in more data" (18.03.22 lns 45-46). Even with the lesser amount of data, the task was still quite daunting. One of the earliest strategies Hannah used was to discuss things with her instructor, who was unfamiliar with KeyLines, but quite familiar with Hannah's abilities as a programmer (18.03.29 lns 62-74):

> Hh: Like it's kind of like [instructor] did say and when I was doing work experience a lot of it is kind of copying pasting but the w- as I said the way they've ranked the data is so different to in the demos and the way I was working with it they've laid it out a lot differently … when we downloaded the code and we were kind of uh following the read-me script to find out how to kind of put it into KeyLines format there was like 7 million reviews and obviously 1) our laptops wouldn't be able to run it 2) we don't want to work with that much data
>
> R: Yeah
>
> Hh: And KeyLines can apparently only deal with like 50,000 nodes so we wouldn't want that much data so we only downloaded I think 100 which is still quite a bit to work through

From this point onwards, Hannah has recognised that she cannot rely exclusively on her previous experience. The line in the quote above, about her going through the read me-script (for converting the parsed data into a KeyLines-friendly format) suggests Hannah has already started to rely on additional sources of information. She indicated she would spend some time working on solving the issue using what she had, and that took her into the half term break.

After half term, which also represented approximately the halfway point of the project, Hannah became less certain of her ability to sort out her issue independently, and so became the first member of the class to email Cambridge Intelligence to ask for assistance, to mixed results (18.04.24 lns 30-43):

> Hh:..I don't think he fully understood what issue we were having and I think it would have been helpful if we understood what he was saying cause he he gave us really detailed even examples and stuff but because obviously we don't code in JavaScript ever apart from this and we don't know the KeyLines APIs and all of that it was just kind of like 'okay you've given us lots of information we just don't know what to do with it' kind of thing umm so it was kind of helpful but kind of not it's gonna take a lot of understanding to understand what he was trying to actually tell us to do
>
> R: Okay um worst case scenario if he isn't able to come in this week and you're having to try to work through this because as you've said this is sort of a barrier to continuing on umm what are you going to have to do to sort of work through those emails?
>
> Hh: Well, we're gonna be doing what we've been doing for the next past two weeks basically just trying to find out how we're gonna reference that data if we can't we're just yeah again going to make no progress I might if we by Wednesday lunchtime if we still haven't got anywhere I'm gonna just have to send him an email again trying to get him to explain more simpler [sic]

By this point, most other groups had abandoned the 'flashier' features such as combos in favour of simpler things they could manage independently, such as changing the colour and shape of the nodes. Hannah had been determined that this was not an option, but reaching out via email did not have the immediate impact she had hoped it would. Hannah was left still having to take his

email advice and compare it to the API reference for KeyLines, as well as the demos, in the hopes she could decipher the advice she had been given.

As has been seen in §5.5.3, the next week brought in the Cambridge Intelligence people, and they were able to quickly fix Hannah's problem. For the remainder of the project, Hannah had only to copy and paste in the code for additional features from the KeyLines demos, though there was evidence of planning and prioritising where necessary. Time then became the limiting factor for the group, having lost several weeks to the combos/node id problem. While certainly this was a different project than the one Hannah had worked on while on work experience, it is harder to classify this final phase as new learning, as once she had figured out how to reference the data, she was using the same strategies and skills as she had previously. Nevertheless, she still felt the pressure to make a product that was not only passable, but more impressive than that of her peers, so her decision-making process will have varied to an extent. The beauty of a project such as these Challenge projects is that even the most ingrained skills find new uses, even for a seasoned veteran such as Hannah.

8.1.3. Jane

While Hannah was working on learning how to call data with similar properties (and indeed learning *how* to learn how), Jane was busy observing and recording all of the details of that journey. Having enough of a CS background to understand the terminology and the basic computing concepts she would be needing to report on, Jane focussed more on the report and presentation, which included a number of new skills for her. Initially, both Jane and Hannah believed that it would be necessary for Jane to help with the coding, and so initially the report and presentation were both meant to be collaborative. The addition of Chris to the group meant that Jane's focus was firmly on the creative end of the project. This did not mean just passively recording what the rest of the group did, however; one of the areas where Jane was the most crucial was in creating and maintaining an image of the client that would allow the programmers to focus their efforts on the features that would most appeal to that client.

This was a new challenge for Jane; while CAST has always made a significant effort to ensure students are taught presentation skills and given help with marketing themselves (for a job or admissions interview, for example), marketing of this type was not something Jane had been

exposed to previously. From the start, she knew that the product design would be critical (18.03.20 lns 18-19):

> R:…is there any one particular thing that you want to be able to work on?
>
> J: Umm like I don't know but maybe like try and get the design like everything like all nice

The earliest focus on design was on creating one that would efficiently allow the client to collect the information that was useful to them (18.03.20 lns 82-87):

> R:…what sort of intelligence would you be able to derive from this that someone would actually want to purchase?
>
> J: Umm like just oops [drops pen] um I dunno just really see what people buy with other stuff what people's reviews are for stuff if it's a good product or a bad product and then then we'll like investors will know like 'invest in this sections of something or like this product or' um yeah just see how people like products are linked from reviews…

This interview, held immediately after the project brief was provided to the students, reveals that initially, Jane's focus was on the intelligence, which is after all what according to that brief she is meant to be selling. By the next week, Jane has plans to sell the data back to Amazon (see section 6.3) and this is the first real evidence of Jane's concern about the identity of the client as well as the nature of the intelligence she plans to sell them.

It was not until several weeks in that Jane began to design her team's Power Point in earnest. That Power Point (Appendix B.5) represented Jane's principal contribution to the project, and so for her it was the main motivator to be learning. In Jane's case, this learning seemed to be taking place in several areas simultaneously; she was learning about others (Fink, 2013) by having to essentially create those others for the purposes of the project. She was having to think creatively about what would most attract these hypothetical others, and manage the project so she could complete it in a timely manner. Jane has always been an organised person, having confided in me once that she almost used organisation and project management to such excess that it become a procrastination tool (18.03.01 lns 91-93):

> J: Yeah I'm good at keeping things organised but I still think I I spend too much time on organising and not revising and like you know? I plan too much just so I don't have to procrastination by organising that's what it is.

With this in mind, it is perhaps not unsurprising that so many different images of the client were seen throughout the project. Jane constantly adapted her views on what her client might need, or what they might find appealing, so in several instances, she had to work to revise previous slides to cater to the needs of the new client. This view helped shape her work, but it also arose directly from her own desire to perform well (18.04.20 lns 80-81): "I don't know if we had to add in like a client in there but it just seemed kind of helpful to have more of an objective on why we're doing this".

It is really this idea, more than any other, that demonstrates what Jane had learned during this project. It's a common tip provided to young writers as they learn to write persuasively that it is important to 'know your audience', and that is exactly what Jane did here. Whether she had ever been given this advice previously I cannot be certain, but wherever the idea came from, it had a significant impact on her work here. The feedback from the judges on the assessment and presentation day was overwhelmingly positive with regards to her coherent focus on the clients' needs.

Jane's contributions to the project were not limited to her creativity, however. She had regular check-ins with the programming team, and was often involved in the decision-making processes regarding which features to add or not add. On one occasion, she did attempt to take on the role of programming a feature, colour-coded nodes based on the reviews. If we look at her behaviour in preparation, she took a fairly logical approach, first "looking at some of the demos" (18.04.30) and then looking through the code of one of her friends. This was in line with the way she would have seen Hannah and Chris prepare for their tasks. Based on this, Jane decided on an if-statement, essentially split into three conditions "if rating >3, green; else if rating =3, yellow; else, red[51]". For reasons unknown to either Jane or to her teammates, this

[51] The syntax here is not meant to constitute proper syntax, but is 'translated' slightly to allow the non-programmer to have some conception of what the code means

failed to change the colour of the nodes, and so her next action was to seek out independent help, from w3schools.com, a website that provides numerous tutorials in several different programming languages.

Though the website, Jane discovers another type of statement, known as switch statements, which she was not as familiar with. At this point, her best option was to consult another member of her group, and she and Chris spent some time trying to problem-solve and get the code working. She had picked up several ideas from watching the resolution of the combos issue, and tried separating the statements out, and checking over the syntax. Ultimately she was unable to make the block of code do what it was designed to do, and she left the task of debugging* to Chris, while she returned to the report. Jane was not particularly disappointed in her inability to complete the task (18.05.11 lns 71-77…88-84):

> R: Okay um and then before you guys did decide to approach this other um strategy for colour coding how much trial and error did you guys go through with that?
>
> J: We did quite a lot of trial and error cause I remember me and Hannah working on it even after when like last not this week but last week we were afterwards just chatting on her computer and trying to like order it around and everything both of us and we just couldn't get it done but we did do a lot of trial and error
>
> R: Um and in the end are you fairly happy with the outcome does it still work
>
> J: Yeah and the halos might even be slightly better because we didn't have that many colours and some of the colours were the same as the node colours for like products for instance so with the halos you can tell it's a review now

Even when she was unable to complete a coding task, Jane still managed to find the positive, in that the reviews were now easier for the client to identify as reviews. During the presentation, this particular feature was mentioned, and so clearly the unintentional outcome is on Jane was able to view as a positive. Despite the project being based in Computer Science, Jane connected with that human dimension, and it is what carried through regardless of the setbacks she faced.

8.2. So what works?

In 2008, John Hattie published a landmark meta-analysis of hundreds of previous studies that aimed to determine what the most impactful teaching practices were, based on effect size. The specifics, while fascinating, are not being discussed in this chapter, beyond the argument that while nearly anything the teacher does will have an effect, far fewer teaching behaviours have a significant or meaningful impact on student learning. He cites Olson (2003) as a reminder that, in the end, the student is the one who determines what they will learn, not the teacher. At the same time, the evidence presented here leads to the conclusion that while teachers must empower their students to learn independently, they must guide them through the learning, rather than loosely facilitating and allowing students to determine their own paths. Throughout the project, evidence of both guidance and facilitation were seen, and while it is not my intention to determine which was *more* impactful, I do intend to consider here what *individual* impact they had in each instance, be this in terms of the development of new content knowledge, skills, or even just changes in attitude or motivation.

8.2.1. How much instructor input is actually beneficial?

It may be obvious from the narrative accounts of each case (chapters 3-6), but the Challenge Projects at CAST varied quite substantially in terms of instructor input. Having previously observed two other projects (a Year 10 project on hydropower dams, and a Year 12 mini-project in Biochemistry), I still cannot say with certainty that the Water Management and Computer Science projects represent the extremes on a spectrum of instructor input, but I can say that the WMP was the most structured of the four, and the CS project the least structured. As can be seen in Appendix A.1, the Water project had specific educational aims for each day, and the instructor prepared numerous activities and provided extensive hand-outs for each session. Students also had a specific list of teaching and learning objectives to hit (Table 3.1), and lessons were designed to cover specific ones at specific times. The CS project also had several listed aims, but these were less specific, and the structure of the project meant that students had more control over what tasks they completed and when.

The structure of the Water Management project varied little from week to week, with the exception of the first week, which was mostly lecture-based (more on this later). The students would come in after tutorial time (Appendix D.1), and they would head for their field location for the day, often the Nine Wells site and points along Hobson's Conduit, but also the school's weather data station or the Anglian Water plant. At those sites, the group would take observations or samples that would then be shared with the whole class. In the afternoons, most of their work was classroom-based, either analysing the morning's data or working in their small groups to complete the report. Hamish was relatively critical of this approach (18.06.11 lns 301-305):

> Hh:…I felt there was a lot of hand-holding throughout the whole thing uh I felt there was either too much hand-holding or not enough hand-holding through certain so we either knew exactly what we were doing and wanted to get on with it or we had no idea what we were doing and just needed some help with it

Hamish's comment regarding not enough hand-holding can be easily traced to a particular incident; he found the session (18.03.21) revolving around the weather data to be quite frustrating. His group found formatting the large amount of data they were given quite a time-consuming task, and by the time they had put it in a form that would be useful for any meaningful analysis, the time had run out. It was during this session where Hamish first explicitly expressed his disinterest in the project, stating it was likely he would just "put in the bare minimum and then just move on to the next project".

There were other days where Hamish appeared to be disengaged; this was the only interview session in which he was so explicit in his feelings. Understanding what did not work in this session is in many ways critical to understanding what did work in others. To begin with, one of the common lamentations of his group was that there simply was not enough time to type up the weather data (Appendix A.4) to be able to manipulate it on the computer. A wealth of information was provided to the group, including a 10-page workbook on managing large data sets, and several policy documents that referenced the role of weather data on water management plans, but the sheer volume of this overwhelmed them, and it was indicated more than once that they lacked the time to read through everything as well as format and analyse the data. This was

a situation in which Hamish would have welcomed some 'hand-holding', as he called it (18.03.23 lns 8-14):

> Hh:… the problem with us is we're given all of this us relevant set of data which to took us flipping ages to format but um then once we'd done that we weren't given enough guidance to then go on to find cause we were meant to be comparing the um the weather here with the standard of the terrain along the um Hobson's Conduit and we couldn't find anywhere where to get this kind of information for um Hobson's Conduit for what the general conditions of it were on these days and then to compare that with the weather so we understood what we were meant to do we just couldn't get there

What Hamish is describing here is more in line with the format of the other challenge days, such as the biotic and abiotic sessions in which data was collected, and then analysed as a group. There was very little 'guess work' involved for the students themselves, and so Hamish could rely on the expertise of his instructor and his peers. Hamish's major issue wasn't with the lack of guidance as to objective, but rather he was uncertain as to whether or not their conclusions would have been correct. His feelings here are actually not uncommon among students new to the PBL model, who often are resistant to the shifting of responsibility for their learning from the shoulders of their instructors to their own and are concerned their independent work may not lead them to the 'right' answers (Kunberger, 2013; Stefanou et al., 2013).

As Hamish had himself pointed out, there was no single 'aha' moment regarding his understanding of Biodiversity, which he did ultimately decide was the main purpose of the project. Despite being quite disengaged by the specific session dedicated to reading up on the topic (the same day as the weather data, but the afternoon), he did from week to week build an image of the project that revolved around this concept. It is worth noting, however, that his first explicit reference to biodiversity did follow this session, with the word being used 24 times in that session. Use of the word 'biodiversity' tapered off after this, but from this session onward, he made this his major focus. Ironically, he was perhaps aided in this by the oft-lamented lack of a printed syllabus for him to reference. The syllabus (which had been available online but Hamish had apparently been unaware), made reference to factors feeding into a coherent water management plan, with biodiversity not even listed in this capacity. In this case, it was the lack

of 'hand-holding' that allowed Hamish to form his own opinions and find a means of engaging with the project.

Within the other project, there were few if any examples of what might be termed hand-holding, with students, mentors, and instructor alike keen to ensure student autonomy within the project. While the Water Management project most closely resembled what Bevins and Price (2016) would likely classify as *structured inquiry* if not *confirmation/ verification exercises*, the Computer Science project contained elements of both *guided* and *open inquiry* (§1.6). The CS project instructor himself was a passionate advocate of project-based learning, which in his mind meant fostering student autonomy to the greatest extent possible; as he once remarked to me "you know project-based learning is working when I don't have anything to do". This does not mean that the project did not have definitive aims, it had as I have shown in Chapters 5 and 6 quite specific aims. However, the instructor firmly believed in providing the students the objectives and resources right away and then letting them find their own way.

For this project, the method was apparently successful, with even the mentors from Arm remarking on how focussed the students were, as well as how much progress they were making from week to week. The instructor's response was that "just because students don't see the aims ahead of time does not mean the project is not designed to meet these aims, which means students feel in control but are still meeting their learning objectives" (18.04.18). It is in this same session that Hannah finally reaches the point where she feels the need to email Cambridge Intelligence and ask for help, which may actually be seen as proof of method; she evaluated her existing resources quite thoroughly and had determined she needed additional help, which she sought out of her own accord. The instructor did not entirely leave the students to their own devices, often offering small, practical tips (Hh.18.04.24):

> Hh: So [instructor] said why don't you print out the source code to one of their demos that we were interested in and try to like look it through and understand what each function's doing what each line of code is actually doing…

In general, though, the instructor felt that since the students were designing their own end product, they were in the best position to determine what steps to take and when as they constructed said product. This may actually prove to be the key difference: when the students

feel they are in charge of determining what the "right" answers are, they are more willing to accept less guidance as they strive to reach them. This will be discussed further on in terms of implications for future research.

That the students did not feel dependent on their instructor to provide answers does not necessarily mean they relied exclusively on their own skills; the students in general felt quite comfortable giving and taking help from one another as the projects progressed. Hannah in particular relished the collaborative aspect of her project (though she sometimes abandoned it when focussed on the competitive aspect), even if it meant working with a less experienced programmer (Hh.18.03.16 lns 53-57):

> Hh: Yeah cause I feel like when you if you're able to explain it to someone else it shows you understand it more which I find really useful it's why I like teaching people almost um so having Jane there for us to kind of teach and help her understand might in fact we might be showing her something and then realise a problem we've made or a bug in the code and it kind of helps us help her and you know it's all kind of interlinking so I think yeah it will be very useful

Jane as it turned out had shared Hannah's optimism for the group dynamics (J.18.03.16 lns 56-59):

> J: Yeah cause we all get on well with each other and I we all have like our good skills we've got and both of them do Computer Science A Level which is more handy cause they have a better like grasp of it but obviously I'm still going to pull my weight and yeah I I think our group clicks and everything

Though their optimism regarding Jane's role in programming (and thus the benefits Hannah might have gotten from teaching her to program) did not materialise after the addition of a third Computer Science student (Chris) to the group, the students were left to restructure and proceed independently, so each student ended up working in a position in which they felt the greatest confidence, and had (according to them) the best potential to learn something useful for their futures.

Because Jane's role as the group scribe and creative director was one that was new to her, she did perhaps require more guidance than her teammates in meeting her objectives. Jane met frequently with the Arm mentors, who were present to be consulted in precisely this capacity. They were of particular assistance as she wrote up the interim report (J.18.04.20 lns 7-14):

> R: Can you talk me through what you decided to put in that report?
>
> J: So to start off with I kind of just had cause I asked someone what they like what [instructor] said to them to do and he was like just put in like what you've done, how you did it, what you need to do, and the difficulties you've had so I kind of did a basic thing of that and then I talked with the guy who came in I can't remember his name but somebody who works for Arm and he just gave me an example like let me look at an example of his and helped me with a more structured layout and it was like business objective and then the source of our code we put in the like we also put in kind of of like our like what we chose to do, how we're gonna do it…

Jane's inexperience with report writing has already been established, so an increased instructor presence in this case was important; there was a correct way to structure the report (Appendix B.7), and so it was important to Jane to get this correct. The group therefore thrived in the project as formatted; it was not that help was unavailable, but rather it was available when they sought it out. For Hannah and Jane, this structure allowed them to explore areas of their own unique interests, but in the end still be successful as determined not only by their own self-evaluation but by a panel of judges from industry.

8.3. Implications

Despite this project showing evidence of learning in each of the cases presented, each of the participants was particularly influenced by different elements of their projects, or certain instructional strategies. Hannah thrived on minimal support unless requested, Jane appreciated having the support readily accessible, and Hamish simultaneously resented what he viewed as hand-holding while also feeling he was on occasion left with fewer resources than he needed.

This may be due to their perception of the aims of their respective projects. Research has shown that students who perceive that their projects have no correct answer are more positively inclined towards autonomy (Kunberger, 2013; Stefano et al., 2013) and would thus likely be less discouraged by the lack of a particular resource. In the CS project, students were actively encouraged to design their own product as much as possible, whereas the Water Management project was working towards a report that Hamish viewed more as an assignment. This is not to say that the CS project was completely free of all constraints and therefore frustrations; because the node id issue did have a 'correct' answer; even Hannah became frustrated with her inability to access the guidance she needed at the time she wanted.

A second concern that did materialise was that Jane, the novice programmer, was not given the same opportunities to develop programming skills as she had initially planned, with Hannah, Chris, and Matthew performing the majority of programming actions. This is also not unusual; Pinho-Lopes and Macedo (2014) found precisely the same situation in their research, where students who came in more comfortable with the tasks at hand were far more engaged with them than their peers. This, as they report, may have increased the overall quality of the final product but meant some group members did not have the chance to acquire the same competences. It is difficult to argue that this outcome was a disadvantage for Hannah and Jane's group; though initially Jane had expressed a desire to better understand programming for its larger societal implications, the language she and Hannah both used throughout the project indicated they both held each role (programmer and reporter) in near-equal regard.

This situation within the CS project may be due to its highly authentic, interdisciplinary nature. While Beier et al.'s (2019) either/or assertion that PBL projects *must* be generated by an external client was rejected in favour of a spectrum, I cannot ignore that the students in the employer-designed and led CS project treated it more like a job and less like an assignment than did those in the WMP. Part of the authenticity in the case of the CS project is based in the likelihood that in industry, there would be separate individuals handling market research, client liaisons, and programming. This meant that each student was developing a combination of both hard and soft skills (Vogler et al., 2018) in an authentic learning environment which allowed those skills to be developed and utilised as they would in industry. Because each participant was able to see the real-world impact their contributions had, I believe this contributed to their attitudes regarding the equitability of their roles and contributions.

If we consider the Water Management project, it is more difficult to argue that the distribution of work was equitable. On numerous occasions, Hamish's absences meant he missed certain activities, or was not present for catch-up and report-writing days. It is not for me to comment on the reasons for the absences, which are irrelevant; my only concern is the impact they had on his contributions to the project. For much of the project then, Hamish was a passive observer rather than an active contributor, which is another common concern about project-based learning (Mills & Treagust, 2003). It is perhaps because of the more prescriptive structure of the WMP, where participants could take on largely similar roles, that Hamish felt it was possible for him to play a less active part in the project when his interest waned. It was only near the end of the project, when the team began to plan for the Primary day, that Hamish began to make efforts to 'pull his weight'. This was a result of Hamish's increased enthusiasm for the activity, which he attributed to a feeling of appropriate autonomy, as well as a general affinity for working with younger students.

While I cannot claim that this will hold true for all students, the projects here suggest that the students who feel in control of their project outcomes welcome autonomy and make efforts to contribute in their teams, allowing them to learn according to their prior knowledge, skills, and strengths. It should perhaps be noted that this should be thought of as prior knowledge, skills, and strengths relative to the rest of the group; in another group, Hannah could have been the least adept programmer and Jane the most adept. They were both explicitly aware that their arrangement was only successful because of the contributions each made to the team, and how their team dynamic shaped their own experiences. Essentially, while the structure of the project will impact what the students learn, the students themselves and their backgrounds will likewise determine these impacts. This is in line with the constructivist underpinnings of both this report and of the project-based learning method as a whole.

It was mentioned in the literature review that not all projects claiming to be PBL will fit the definition. Putting aside the difficulty of there not being one single agreed-upon definition (Mills & Treagust, 2003; Thomas, 2000), each element of the definition being offered here is up for debate. As a reminder, that definition offered in the literature review was: *an authentic, real-world project that is central to the curriculum and requires active student involvement in the production of a final product or artefact.* Because of the flexibility of some of these terms, in particular 'central to the curriculum', 'active student involvement', and 'final product or

artefact', many teachers may naïvely believe they are offering true PBL to their students. I myself was guilty of this, offering what I believed to be innovative projects, but that lacked any student choice in their design. And if you define a lab report as an artefact, I could have termed every laboratory investigation as PBL, no matter how prescriptive.

So, how am I certain that these two projects count as PBL? They are certainly central to the school's curriculum; the entire timetable is built around the Challenge projects, and the transferrable skills developed there are central to the mission of improving employability after the completion of studies. The degree to which the student involvement was active certainly differed, with more prescribed activities in the Water Management project than the Computer Science one. This is not unexpected; projects will, in order to fulfil other characteristics or in the interests of safety, differ in the level of autonomy offered, as was seen above. In both cases, however, students were more involved than in a traditional, lecture-based course, situating the students in a situation of 'doing science' (Novak & Krajcik, 2019) rather than passively absorbing it. For projects in which the focus is the construction of new knowledge, as well as the application and development of existing knowledge, there may be by necessity greater input from the instructor, particularly in the early stages. This could certainly account for the differences here, as in the Water Management project, neither the BTEC students nor the A Level students taking Biology had not yet been exposed to much Ecology, where in the Computer Science project, all but two or three had already developed programming skills in multiple (programming) languages.

Where there can be little doubt about these two projects is in designating them authentic, real-world projects. If we accept Thomas (2013)'s focus on outcomes relating to 21st century skills both of these projects had the potential to allow students to develop multiple skills that would be useful in their future paths. These skills were in all three cases a combination of transferrable 'soft' skills and industry specific 'hard' skills, along with changes to their conceptions of the topic or phenomena being worked with. While Hamish's conceptual changes tended on many occasions to overshadow his technical or transferrable skills development, he did have opportunities to attempt to process and analyse quantitative data, learn field sampling techniques, and help write a scientific report. Jane's technical skills were less based in Computer Science and more focussed on market research and graphic design. This does not mean that she did not experience conceptual change; her evolving image of the client is evidence of this.

Hannah continued to build her computer literacy, refining her process for debugging code and using API references to help her build a serviceable product. This required not only self-direction and determination, but a combination of technical skills and growing conceptual understanding of the rules of computer programming. That each participant's narrative focussed on a different type of learning may be considered evidence of the individualised nature of such authentic projects.

Students also learned these skills in undeniably real-world contexts, with both projects mirroring the development of a similar project in the local workforce. While the CS project may have offered *more* opportunities to do so, both projects also allowed students direct contact with that workforce, and the chance to seek advice or opinions from those who engage professionally in the work in which the students were temporarily immersing themselves. This is not something that can conceivably be done in every school, as the logistics involved can be quite complex (in this context, the school has designated personnel to liaise with local employers and arrange the Challenge projects). However, a project need not have daily oversight from the real-world industry to be a real-world project. By considering the other factors, and aiming to develop the real-world skills, instructors that are so inclined can certainly design a project that meets the criteria for PBL.

8.3.1 Final thoughts

What are the take-away lessons from these three cases, assuming an appropriate PBL project has been designed and is being put into action? How do students learn during PBL projects, and what effects do the different aspects of PBL have on that learning? Because the research questions guided the research that led to this thesis, it is the answers to these two questions that I believe to be the most crucial:

1) How do students learn while engaged in project-based learning in secondary science?

Perhaps the biggest take away of this research is that no students learned in the same way, or even the same things. The benefit of the case study, and the observation and interview protocol, was that it was possible to follow each participant's learning in some detail. In the case of Hannah, who was arguably the most invested in the published aims of her project, there were several points in which her learning deviated from what was expected. She learned to handle unexpected issues efficiently, and to delegate where necessary. Her recitations of her struggles and the strategies she used to overcome them provided detail on the learning that didn't make it in to her team's final report. Jane developed few new programming skills, though certainly by writing the report she is now more aware of what struggles a programmer may face. This formal report writing was new to her, so she had to develop that skill as well. Perhaps most meaningfully, she developed a client to whom her team could market their product, which certainly added an additional layer of authenticity to her work.

In the cases of both Hannah and Jane, their most obvious learning was more skills-based (Fink, 2013); with Hannah's work leading predominately to changes in her procedural knowledge (Anderson et al., 2001), but problem-solving (Vogler et al, 2018) certainly played a large role in her experience. Jane's experience was also largely skills-based, in her case relating to developing a client and marketing to them, while also following her group's progress and writing up a report. This may appear to be primarily transferrable skills, but her research and marketing may certainly be considered a technical skill. What was less explicit was any change in conceptual knowledge, at least on the surface. If Anderson et al. (2001)'s taxonomy is considered again, the processes of problem-solving, evaluating for write-up, and creating a final product may be seen as moving within knowledge dimensions, thereby supporting the assertion that changes in conceptual knowledge, technical/procedural skills, and transferrable skills were all necessary to complete the CS project.

Hamish's experience with his project was quite different to Hannah and Jane's and so too was his learning. In his case, while there were opportunities for the development of skills both technical and transferrable, Hamish's learning was most obvious in terms of conceptual change and development. While the project brief (Appendix A.1) mentioned a few skills-based objectives, the majority focussed on developing an understanding of relevant concepts. Perhaps because he either did not see this brief or had forgotten about it, Hamish came up with his own detailed yet radically different interpretation of his project. He came to the project prepared to

care about water management for people's sake, but found himself engaged far more by ways to minimise human impact on the environment.

Biodiversity, what had been considered only one of many factors influencing or indicating the health of an ecosystem, became his focus into which all other knowledge and skills flowed. This perhaps best fits with Özdemir and Clark (2007)'s knowledge-as-elements perspective of change, in which change takes the form of evolutionary revision, refinement, and reorganisation. Even Hamish acknowledged that much of this reorganisation was contextual, with priorities and attitudes changing from week to week. This agrees with Wittrock (1994)'s views that learning is activated in different contexts. Wittrock's assertion that the contexts be as realistic as possible will be explored more below.

2) What effects do different aspects of project learning have on the learning taking place?

Where PBL is implemented, students are empowered to take control of their own learning, and this means they may be critical of their learning or the methods through which they are taught. Hamish in particular was very vocal about whether he felt interventions were appropriate to help him meet his targets. Hart, a Year 10 student consulted regarding his project[52], was also quite aware of the impact of certain lessons on his learning outcomes. They were not afraid to challenge the current system where they felt it was not working, but they were proactive about it, and in a culture of mutual respect, such challenges were well-received and student needs were met. Hannah was another example of this; she worked through all available resources, and made requests for increased support from the programming experts where necessary. This ties in to another very important point-even in a project that is predominately led by the students' own initiatives, what the instructor says or does matters. While Jane in particular seemed to thrive on her independence and her ability to plan and work at her own pace, the support from the mentors gave her enough guidelines to be confident in her final report. Every instance of direct instruction, facilitation, redirection, or guidance is impactful, and care must be taken to ensure that impact is a positive one.

[52] Hart was part of the engineering project discussed in §7.4. He kindly agreed to participate in a number of interviews to provide me with perspectives on the UTC Challenge Project at a different age group

8.4. Recommendations for future research

The literature review (Chapter 1) provided a great deal of guidance for the collection, analysis, and presentation of data in this thesis. However, it also highlighted a particular gap in the research; the majority of published research into PBL (§1.5.1 and 1.5.1.a) focusses on university students, either those already specialising or those in introductory courses. The reasons for this are not often made explicit in the works, and are not of great import here. What is important is that prior to this, relatively little work had been done to examine student experience in long-term PBL projects at the sixth form level. In particular, until McCrone et al. (2019) published their report on UTCs, no published research into the experience of students in the UTC model of PBL had been made available, and certainly none where the cases were individual students, rather than the programmes in which they were participating. It is likely therefore that this thesis represents the first case studies into student learning through PBL in the UTC context.

Another feature that is unique to this work is the detailed analysis of individual student narratives, allowing for a much more detailed understanding of student experience within PBL than has previously been made available. Many case studies tend to define the case as the programme, rather than the individual students within that programme. The trade-off for this depth is a loss of generalizability, but it does offer a previously unexplored series of perspectives of students at every stage of a longer-term PBL project. It is imperative, however, that such perspectives be sought in a wider range of contexts to provide a more complete picture of student experience in PBL projects. The CAST model is relatively unique within UTC's, and UTC's themselves are a unique form of secondary school within the UK. This work, while informative, is limited to one highly specific and STEM-specialised context, and follow-up work in other school types would only enhance our understanding of learning within PBL projects.

The potential for year-long or even multi-year studies with a subject also has its appeal. Due to practical reasons, this was not feasible for this thesis, but such an extension would perhaps provide a better understanding of which understandings and skills developed in one project might be transferred to another project. One of the observations made in this research

was the development of *transferrable* skills alongside subject-specific ones; a more longitudinal research project would perhaps shine light onto which skills the students themselves feel are most applicable and useful in further projects.

Finally, further exploration of the link between student autonomy and student attitudes towards the projects would prove beneficial in terms of understanding how the structure of a project can influence student experience. The participants in this research, Hamish in particular, felt compelled to on a fairly regular basis comment on their feelings regarding their perceived autonomy or lack thereof. While three cases are not enough to conclusively state a link between autonomy and student attitudes towards a project, the possibility is there, and further exploration of this element of PBL would surely be a worthwhile venture. Given that research already suggests a link between student perceptions of the existence of a 'right' answer and their autonomy (Kunberger, 2013; Stefano et al., 2013), the role this plays in PBL projects such as Challenge is certainly worthy of greater consideration.

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APPENDIX A-PROMPTS FOR INTERVIEWS
A.1 Water Monitoring Project Syllabus (CAST, 2018)

Water Management Project

Outcomes

Produce a management plan for a local river
Make a catchment conceptualisation map
Deliver an event for primary school students based upon water management

Learning objectives

Learn a range of biotic and abiotic sampling and analysis techniques
Understand how biological, chemical and physical measurements can influence the health of a river.
Be able to break down and understand a complex ecosystem
Understand how competing pressures impact upon a river
Understand how human needs can put competing needs on a river
Be able to weigh up complex and competing needs to reach a workable outcome

Teaching objectives

Develop skills in managing a group when not all members are present and able to work directly together, including planning ahead, sharing data, presenting data to the rest of the group so all are aware of how the project is developing
Understand how modern data collection techniques can aid data collection in the field
Be aware of the safety issues associated with field work
Be able to present results to a mixed audience
Develop teaching skills

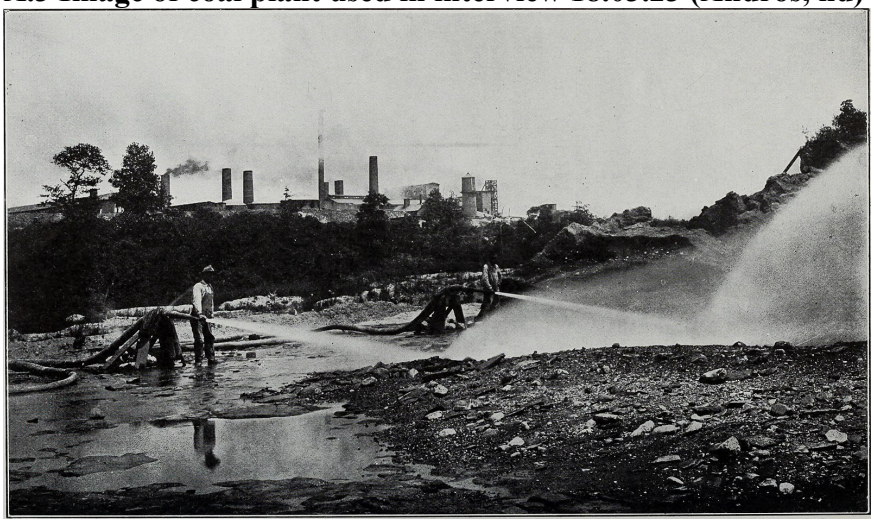
9.35-3.40 (break 10.25-10.40, lunch 1.10-2.00)

Wednesday 7th March	Introduction (Peter Landshoff, Steve Boreham?)
	Students research issues facing the water industry (drought,
	treatment, catchment management, funding) (intro from CBC)
	Students feedback and panel discussion with experts (Martin, Jenny,
	Peter)
Wednesday 14th March	Walk Hobsons Conduit (Jenny, Martin, Hobson Conduit Trust)
	Produce catchment conceptualisation maps
Wednesday 21st March	Analyse weather pattern data and conservation
Wednesday 28th March	Biotic Factors (Environment Agency)*
Wednesday 18th April	Abiotic factors (martins contact)*
Wednesday 25th April	Visit water testing lab and Eddington (Martin/Jenny)#
Wednesday 2nd May	Write river management plan#

A.2. List of commonly used terms offered to Hamish as an interview prompt, 18.05.14

ANIMALS	BIODIVERSITY	COMPETITION
CONSERVATION	CONSUMPTION	DECAY
DEGREDATION	DEVELOPMENT	GROWTH
HABITAT	MAINTENANCE	MICROORGANISMS
NEGLECT	PLANTS	POLLUTION
RUNOFF	WATER	WILDLIFE

A.3 Image of coal plant used in interview 18.03.23 (Andros, nd)



A.4. Sample of weather monitoring data presented to students on 18.03.21

Date	Time	Temp: Inside	Temp. outside	Humidity outside	Humidity Inside	wind speed	wind direction	Rain height	Atm. pressu
01-11-17	07:45	25	09	93	38	3	S/SW	0.0	10202
02-11-17	07:45	26	07	94	29	3	S/SW	0.0	1014.4
03-11-17	07:45	23	10	92	40	5	S	0.0	1014.5
06-11-17	07:50	26	01	94	22	5	S	0.0	1025.1
07-11-17	07:45	27	10	83	28	6	S	0.0	1018.2
08-11-17	07:45	27	06	89	26	3	N	0.0	1022.8
09-11-17	08:00	23	08	68	31	8	S/SW	0.0	1021.9
10-11-17	07:45	26	11	90	33	8	SW	0.3	1016.1
13-11-17	08:46	27	07	84	19	5	W/NW	0.0	1024.7
14-11-17	07:55	25	08	91	29	8	SW	0.4	1021.8
15-11-17	07:46	23	10	94	42	3	W/SW	0.4	1023.6
16-11-17	07:45	26	11	92	37	6	SW	0.0	1020.5
17-11-17	07:46	0/24	01	94	25	5	SW/S	0.2	1016.7
21-11-17	07:46	25	12	89	40	14	SW	0.0	1019.1
22-11-17	07:46	23	14	82	42	19	S	0.0	9988
23-11-17	07:46	22	11	82	464	18	W/SW	0.0	9911
24-11-17	07:46	25	4	93	27	3	W/SW	0.0	1008
27-11-17	07:50	24	09	92	33	11	W/SW	0.8	1011.5
28-11-17	07:46	26	04	90	24	3	W/NW	0.0	1007
29-11-17	07:45	27	03	86	20	10	NW	0.0	1007.3
30-11-17	07:45	20	00	80	22	08	N/W	0.0	1010.3
01-12-17	07:45	26	02	90	22	11	NW/N	0.2	1018.5
04-12-17	07:45	25	02	95	25	03	SW	0.0	1021.
05-12-17	07:45	22	07	85	32	06	W/SW	0.0	1024
06-12-17	07:45	22	08	80	33	08	SW/S	0.0	1028.3
07-12-17	07:46	25	11	89	36	21	S	0.0	1025.3
08-12-17	07:47	26	02	87	21	08	SW	0.0	1011.5
13-12-17	07:45	26	04	94	25	10	SW/S	0.2	998.
14-12-17	07:46	25	04	84	21	11	W/SW	0.0	990.
15-12-17	07:45	21	02	91	27	05	NW	0.2	992.5
18-12-17	07:45	25	03	88	22	03	NW	0.0	1005

A.5 Image of dam used in interview 18.03.23 (Sixflashphoto, 2017)

A.6 Computer Science project brief

Industrial Cadets

EDT Inspiring future engineers & scientists

EES APPLIED BRIEF 2018

Overall Vision: -

"Connected data is all around us –

it is in financial transactions, communications records, IT Networks etc".

Cambridge Intelligence

Each team will be provided with a set(s) of data which will need to be analysed to identify these connections. The teams are required to highlight a need that the analysed data identifies and then come up with a reason why an organisation will invest in, or purchase, either the solution to the problem identified or the intelligence that they are able to provide.

Overall Scope: -

Teams will be provided with raw data which will need to be analysed to look for trends, underlying issues etc. This will be done using Cambridge Intelligence's KeyLine's Toolkit. (*KeyLines is a JavaScript software development kit (SDK)).*

The analysis should identify common themes that can be used as a business opportunity that the teams need to develop and, ultimately, come up with a business proposal to pitch to would-be investors or potential customers.

The Options: -

The are two options for you to chose from. The first is "selling" the information that you glean from your data analysis to interested third parties. The second option involves you identifying an issue from the data and then coming up with the solution yourselves.

Option 1 – Selling the "Intelligence": -

Having identified a trend, or underlying issue, in the data you should consider how to market this information to investors or potential customers. This should include a user-friendly product, accessing the data analysis on a one-off or an ongoing basis, that can be sold commercially or pitched to investors.

Option 2 – Selling the Solution: -

Identifying a problem, or business opportunity, that the data highlights and then creating a solution than can be marketed. For instance, if the data evidences areas of weak Wi-Fi signals, is there a way of overcoming this – by flagging up those areas, creating boosters etc.

arm

Cambridge Intelligence

Industrial Cadets

EDT Inspiring future engineers & scientists

Things to Consider: -

The team should consider themselves as a business start-up in terms of this project.

The Project comprises the following: -

- Analysing the data provided to look for underlying trends or issues.
- Identify a market and create a workable product to be marketed to potential customers or investors. This can either be "intelligence" gained from the analysis or a solution to the problem identified.
- If looking at selling the "intelligence" think about what information you are able to provide and how to add value by building in information from other sources.
- Do you need to change the behaviour/expectations of people? Can you do that with technology alone?
- As well as the technology what else do you need to provide? For example, training materials, a Help Desk etc.
- How can you market your product? Think about what the benefits are, how much is it going to cost to develop and what time frame are you looking at if you are approaching investors? Or, how much are you going to sell your product for if you are going into a commercial market?

This Programme is being funded by arm

and has used software provided by Cambridge Intelligence.

EDT is grateful for their support.

arm

Cambridge Intelligence

A. 7 Roles and responsibilities from the EES applied students' handbook

The ESS-Applied Roles.

Student Responsibilities.

EES-Applied is challenging and encourages both individual, and collective, responsibility for the project. Teams have a STEM mentor to guide them in the application of skills, and disciplines, pertinent to the business and industry sector they work within. Teams, and specifically the individual students, will be working on the EES-Applied project and they will need to ensure that they can fit the work required around their other educational / after-school commitments. Students must also be prepared to commit to attending regular meetings with other team members.

The written report aspect of the project will take a significant level of work to produce. New terminologies in science, engineering and many technical aspects will be required.

Teams will need to make themselves aware of deadlines for specific actions within the overall project. It is essential that these deadlines are adhered to, with the submission of the report two weeks prior to the CAD being a key element. To help facilitate this, guidance in project management will be provided to all students participating in EES-Applied.

The assessment criteria requires each student team member to participate in all aspects of the scheme. Every individual will be expected to contribute to the written report, the oral presentation, as well as the subsequent questioning session.

The Role of the Mentor.

- ✓ Informs the teacher, and students, about careers in engineering;
- ✓ Works closely with the teacher throughout;
- ✓ Makes regular contact with the team by meeting/telephone/e-mail;
- ✓ Attends all Scheme events;
- ✓ Encourages and motivates the team;
- ✓ Identifies a Company Assessor for the Scheme's Celebration and Assessment Day (CAD);
- ✓ Ensures that copies of the Project Report, and the Project Summary, are compiled and dispatched as directed - information on this will be available later;
- ✓ Helps the team prepare fully for the assessment, and presentation, at the CAD;
- ✓ Gives the project due recognition in any company/organisation publicity.

The Role of the Teacher.

- ✓ Works closely with the engineer as a facilitator and supporter;
- ✓ Progresses the students' work when in school/college;
- ✓ Attends all Scheme events, arranging transport when required;
- ✓ Ensures that students balance their school/college work and the Scheme project;
- ✓ Ensures that copies of the Project Report, and the Project Summary, are compiled and dispatched as directed - information on this will be available later;
- ✓ Assists the team to make further presentation(s) to other students and senior managers, and to engineers at the link company;
- ✓ Gives the project due recognition in any school/college publicity.

A.8. The EES Applied timetable, used as guidance for CS student progress.

Industrial Cadets

EDT Inspiring future engineers & scientists

Your EES - Applied Timetable 2018.

Dates	Suggested Activities & Key Dates.	Make a Note of Your Progress	Mentor Support Required.
14th March 2018.	**LAUNCH DAY.** Introduction to the programme, companies and project briefing; Introduction to Industrial Cadets; Team building activities; First Team Meeting - Initial planning session with mentors; Work out, with your teacher, communication channels with your mentor(s); Technical Briefing by Cambridge Intelligence.		
21st March 2018.	**UNDERSTAND YOUR PROJECT BRIEF.** Brainstorming: Agree your roles; Preliminary Time Planning; Brainstorm possible solutions to your project brief. Remember to start creating your documentation – you'll need all of this to go into your EES-Applied report.		
28th March 2018.	**RESEARCH YOUR PREFERRED SOLUTIONS!**		

arm

Industrial Cadets

EDT Inspiring future engineers & scientists

4th & 11th April 2018	**EASTER HOLIDAYS**		
18th April 2018.	**RESEARCH YOUR AGREED SOLUTION.** Do you have everything you need for the 'test and build' weeks?		
25th April 2018.	**TEST IT, BUILD IT.** Do you need to make any changes? Have you thought of any improvements? EDT presentation on CAD requirements including presentation skills and display stand requirements. **Mid-Scheme Review with Cambridge Intelligence (Afternoon)**		
2nd May 2018.	**ARE YOU STILL ON TRACK?** Use this as a period of reflective learning. How are you doing? Have you had any new thoughts? Start writing your report. Send the first draft of your report to your mentors.		
9th May 2018	**REVIEW REPORT, PRESENTATION ETC.** Remember at the end of this week you'll need to send your finished report to c.williams@etrust.org.uk; Draft/story board your presentation; Start working on your display stand.		
	AGREE YOUR APPROACH AND WRITE YOUR PRESENTATION.		

arm

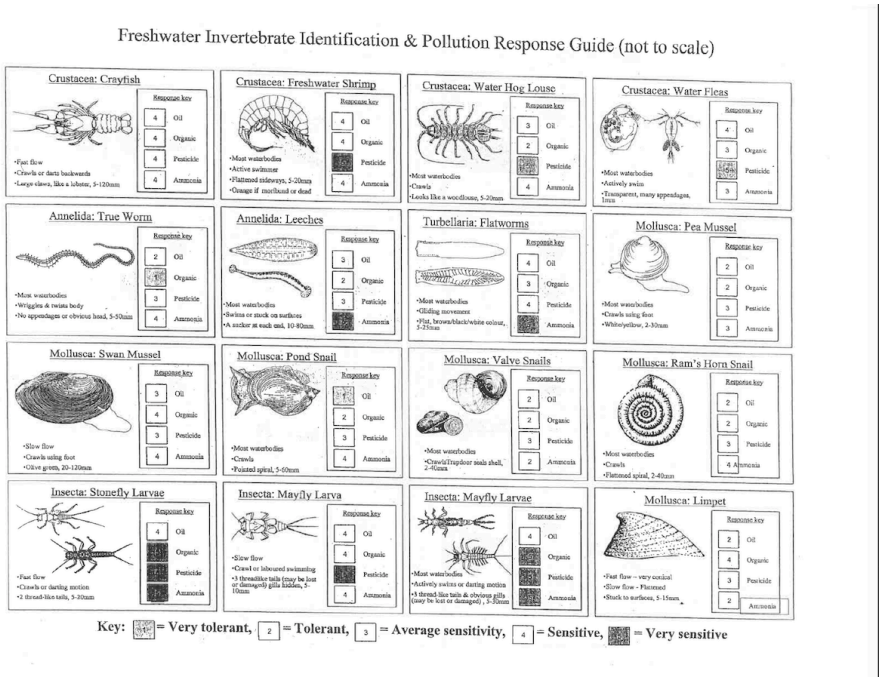
Industrial Cadets

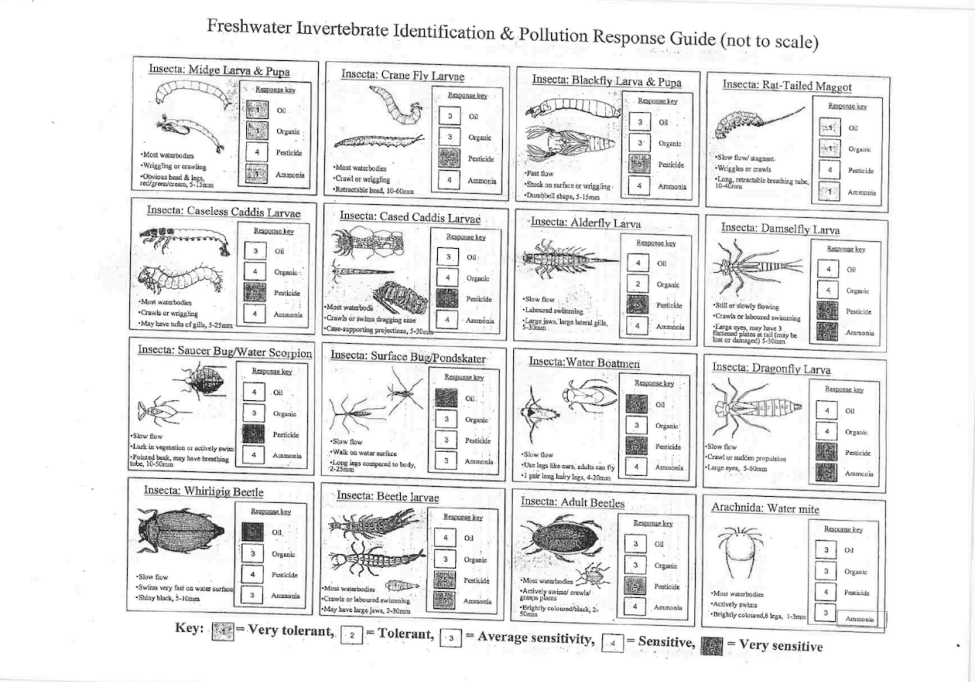
EDT Inspiring future engineers & scientists

16th May 2018.	Practice your presentation in front of as many audiences as you can; Finish off any alterations to your model and display stand.		
23rd May 2018	**LAST PRACTICE OF YOUR PRESENTATION AND FINALISE YOUR DISPLAY STAND.** **Leading to CELEBRATION & ASSESSMENT DAY / INDUSTRIAL CADETS GRADUATION ON 23rd MAY 2018.**		

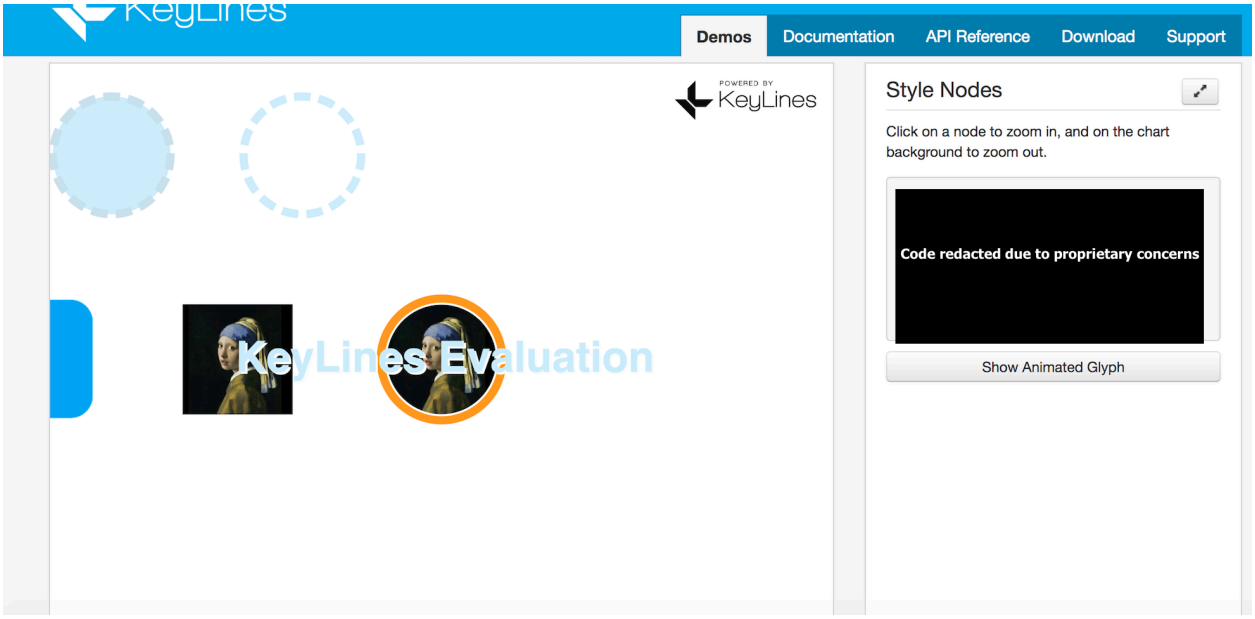
arm

A.9 Invertebrate identification and pesticide sensitivity sheet, used in interview with Hamish on 18.04.23





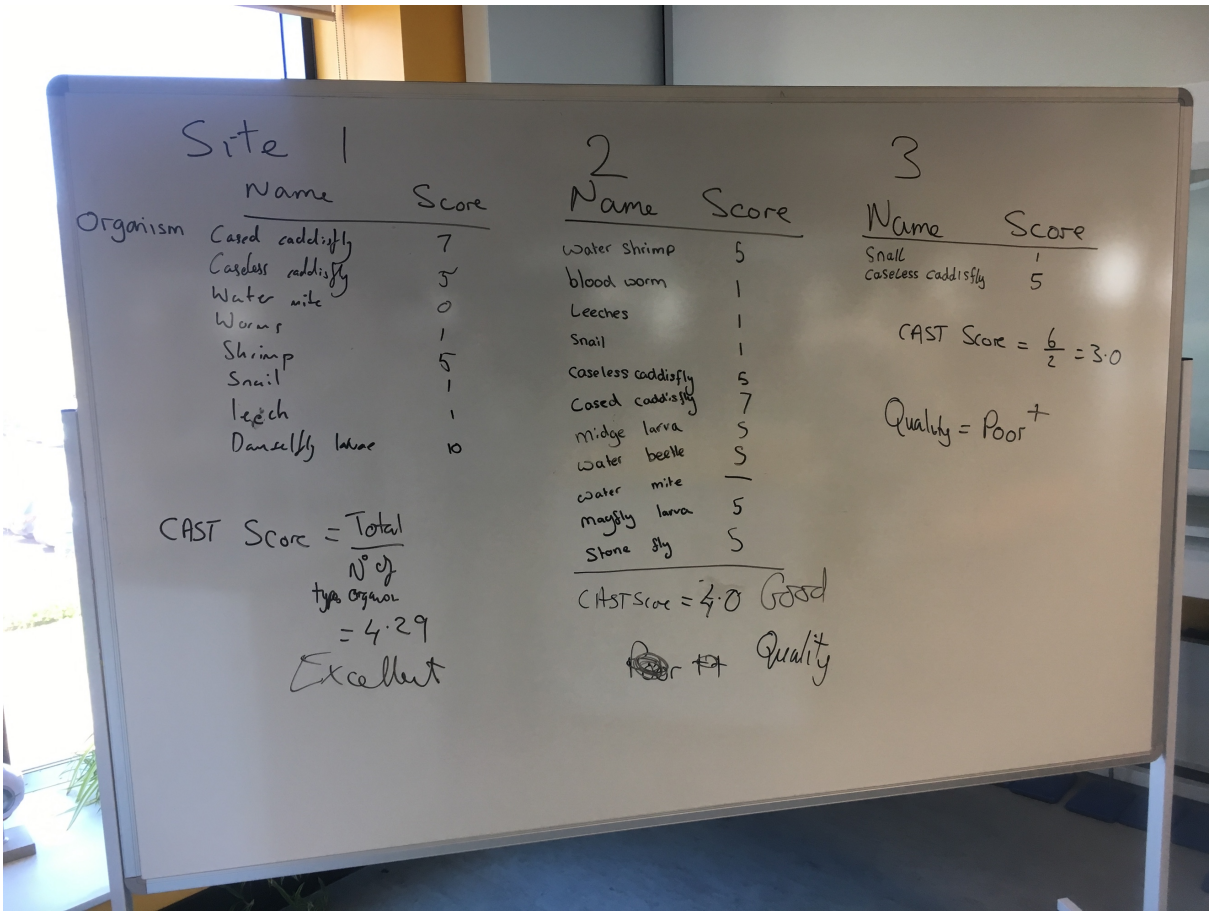
A.10. Keylines demo for node formatting with code redacted to protect proprietary information



A.11. Images used in interview with Hamish on 18.03.20

APPENDIX B-STUDENT-GENERATED ARTEFACTS

B.1 Compiled aquatic invertebrate data collected by the water management students on 18.04.18



B.2 Results of construct repertory test conducted with Hamish on 18.04.16

	1	2	3	4	5	6	7	8	9	10	11	12	13	14
ANIMALS	Y	Y					Y							Y
BIODIVERSITY	N	N											Y	
COMPETITION			N						Y					
CONSERVATION								Y	Y	Y	Y			
CONSUMPTION			Y											
DECAY					Y	Y								
DEGREDATION				N										
DEVELOPMENT			Y							N				
HABITAT												Y	Y	N
MAINTENANCE										Y	N			
MICROORGANISMS						Y	N							Y
NEGLECT				Y	N						Y			
PLANTS		N					Y					N	N	
POLLUTION				Y	Y	N		Y	N					
RUNOFF								N						
WILDLIFE	Y											Y		

B.3 Timeline of Hamish's explicit descriptions of biodiversity, with significant portions highlighted in context

Date	Quotation(s)
18/03/23	Okay umm well my idea I don't actually know the definition of biodiversity I've been fairly winging it halfway through um I do that a lot but yeah my my idea of biodiversity is simply the diver- or the range of um species/ well yeah mainly species whether you're talking about organisms or plant life the range of which you have in a certain environment that that would be my assumption as to what it is um
18/04/16	biodiversity it's quite literally in the name you have a diversity of the different biology of the area meaning plants, animals, whatever um so I umm I think I would link yes I would link habitat and biodiversity here in the sense that um I don't really know to be honest again they are quite broad terms I'm trying to think for a better reason to link them other than the fact that they're both quite broad um but certainty the title habitat encompasses a lot of pieces of information so you know um environment, species that live there, conditions of it and biodiversity is also encompasses a lot of different information
18/06/11	I don't know if I could give a sentence definition of it um just I I haven't thought enough about it or anything um but it encompasses it's a word that describes and encompasses um the variation in different organisms, plant life, um and habitats that will come under either a certain area or a set piece of land or something like that or it can get more specific like biodiversity doesn't necessarily describe a specific habitat it could describe a group of habitats it could be really specific it could be just one area of a habitat but it it's used to describe the variation and the different yeah different numbers or organisms and plant life
	Well like I said I mean the variation so how many different um kinds of species are there um what is the population of each of these species um why not necessarily why might this be because biodiversity isn't well I suppose it could be but if I just said biodiversity I wouldn't be looking for an explanation as to why I would just be looking as to what and so it doesn't necessarily the word biodiversity doesn't necessarily have to give an explanation for what it's findings are it just gives what they are so the different the variation the population um I suppose to an extent you could say the conditions of the of the place although I would tend to stick with more to the living organisms
	just the thing that makes it a key factor is that it's there, not necessarily that it interacts with the other ones
	Okay so I to be honest it was rarely a part of my vocabulary before we started this project just cause it didn't need to be um and so in all honesty going into this my view of biodiversity was very simple I simply viewed it as the changes you find in an environment throughout this project then I have gained a more or a better insight into what these changes are uh and specifically more than just changes what specifically is it and now I've been able to sort pinpoint it's the variation in these it's the greater population it's the presence of this it's the lack of this um yeah it it and so I think beforehand I simply viewed the word biodiversity as a way of describing the changes whereas now I would say um biodiversity explains how um an ecosystem is able to uh keep on well living I suppose well whether it's decreasing in number or increasing in whatever it's simply how it works so all the different factors that mean it can sustainably grow

B.4 Final report written by Hamish and his team (Screenshots taken from PDF to avoid identifying information in header/footer)

Water management report

Introduction

Water quality, of nine wells and hobson's conduit, has decreased over the years due to diffuse urban pollution. This project focuses on the improvement of the water in certain locations along hobson's conduit, shown in the contextual map. There are other factors such as drought and flooding that affect the quality of water and habitats in this area. There are certain species such as floating pennywort which have reproduced on mass over the river, acting as a barrier between the water and surrounding environment causing the levels of light and oxygen present to significantly decrease and making it hard for other species to grow. This affects the biodiversity of the river due to the organisms not being able to sustain with these lowered levels. This has a further degrading effect on the water quality, due to the lack of plants no longer absorbing nitrates or phosphates which as a result remain in the water bed.

During this project we traveled to Ninewells and along Hobson's brook. We first went to look at the difference in river quality and management at different points in the river and how it changes as you travel closer to the centre of cambridge. The next time we traveled to the river was to collect abiotic samples at different places down the river to see if there was any change. The final time we went to the river was to collect biotic samples. These can then be used to measure the quality of the river at different points because certain species require a good quality of water to be able to live there.

Hobson's conduit history

- 1574 andrew perne worried about plague outbreaks wrote to lord burleigh. It was suggested to take the weather from the vicar's brook.
- By 1610 the new river to cambridge was built and assigned to the care of university and town.
- 1631, thomas hobson bequeathed land to provide an income to maintain the public water supply.

Previous Studies/observations of the area include:

- In 1940 and 1970 E. A Grey concluded there was a decrease in the biodiversity Hobson's Conduit could support, due to the rise of intense agriculture in the catchment area and increase in abstraction.
- He also documented a reduction in the average flow rate from 50 l/s in 1949, 12 l/s in 1965 to almost 0 l/s in the summer of 1976.
- In 1980 Fiona Macallum observed and confirmed that the rare rellic species were no longer present, this documentation caused the areas SSSI status to be revoked

Weather

The weather can have a large effect on the river it can cause it to dry up and kill life forms that may be living there and also flood and cause life forms living there and people living nearby problems. Both of these problems do not help us or the conservation of the rives life and diversity.

Back in 1976 there was a drought that affected the Nine wells area very significantly. Before this drought Nine wells has a SSSI status which meant that it was under environmental protection because of a species of rare flatworm called Crenobia alpina and a rare cased-caddisfly called Agapetus fuscipes these were recorded before the drought. Through late 1940 to late 1970 the flow rate of Hobson's conduit was recorded and there was a decline from 50 Liters/second (l/s) to nearly 0 l/s. This meant that the rare species of flatworm and cased-caddisfly were lost due to there not being enough water available, due to this the SSSI status was lost and development was able to happen in the area. In 1980 nearly 5 years after the drought ninewells was still low on flow rate at only 10 l/s and the rare species of flatworm and cased-caddisfly where still absent. This time period just shows how big of an effect the drought has had on the wells.

Although the drought had a large effect on the rivers life and flow rate a large amount of rin in a small period of time can do opposite effects that can equally devastating. High amounts of water can cause floods on the fields and and overflow of the rivers. The flooding of the fields can cause a lot of the nitrates to flow off into the wells and rivers this will cause the water to have high nitrate levels and can cause a lot of the species to be killed off as they will not be able to live in those conditions. Although this is unlikely to happen up by the wells if it does it can have a very significant effect on the later part of the river. The rivers overflowing can also have an effect on the creatures living there. When the river overflows the creatures can get raised with the water and abandoned on the soil when the water finally dissipates causing a fall in the population of that species. The overflow can also cause the nitrates from the soil to be brought into the river which can kill of species as well.

Method

Kick sampling- this is when a net with a flat bottom is placed on the bed of the river. Kick the floor with you foor and let the dust and stones go into the net. The creatures are then caught in the net. The net is emptied into a tray. Do this 3 times. Move the water and stones another container. Look at each animal under a microscope and record what it is.

TETRA test- This is a strip with different indicators that changes depending on the amount of the different things in the water. This tests pH, nitrates, chlorine we did this by inserting the strips into the water samples that we collected we then took them out and left them for 60 seconds so that the colours can change. We compared the colours with those that are on the tube and got the concentrations and pH.

Risk assessment

Hazard	Risk	prevention
Water safety issues	Depth, flow rate, uneven river bed.	Awareness, appropriate foot ware.
Bites/ stings/ irritants	Plants/ animals.	Awareness.
Exposure to disease and infection	Via open wounds coming in contact with the water or plants, water born disease.	Wear protection over the wounds. Gloves/water proof plasters Lyme's disease Tetanus Weil's disease See more information below
Slips trips and falls	General access to water course and in water course, avoid environmental debry.	Awareness, clothing, boots with mid-sole protection.
Weather	Heat, sun, wet, cold.	Awareness, correct clothing and spare set, sun cream spf 15+, drink (warm or cold), check weather forecast, remember some rivers can be flashy and rise very quickly.
Traffic	Vehicular movements	Awareness
Public	Other activities, Threatening behaviours.	Awareness and communication, Awareness; leave the site for personal safety.
Risks to the environment	Disturbance of silt and mud (downstream pollution), Spread of infection to / from other water courses, Spread of alien / invasive species to / from other sites, Distress to fish and other wildlife e.g. Disturbance of fish spawning sites and nesting birds.	Awareness and knowledge, Disinfection, Follow Government guidelines.

Section 3

At this park of the river the water travels slower and slower the further it gets into the centre of town. There are ducks on this point showing that it is traveling slowly because they like to sit in still water.

The banks at this point of the river has been artificially widened and have been help up with wood an bricks in some places. This is done because the water feeds the lake in the botanical gardens so more water is needed to feed it. This has been man modified.

Section 2

At this point in the river the water is moving fairly fast but there have been human interventions that have sped it up even more.

One of the things that we have done is introduce trees and tree trunks into the river to make it thinner at some points. This means that the water will speed up at these points.

There have also been small lips added to the river to increase the flow in one side of the river and decrease it in another this is so that there is a diversity in the ecology of the river.

Section 1

At the start of the river the water originates from underground wells that enters the river through springs. The springs are generated from underground and exits from cracks in the chalk on the surface. Because the water spends so much time in the chalk it is always at 10.2°C no matter what the outside temperature is.

In the field alongside the river are flow diverters. They divert the water from the Babraham institute into Hobsons conduit, attempting to increase the flow.

The river is largely shallow here, and the flow is between 5 and 10 metres per second, which is too low to support the demand for water.

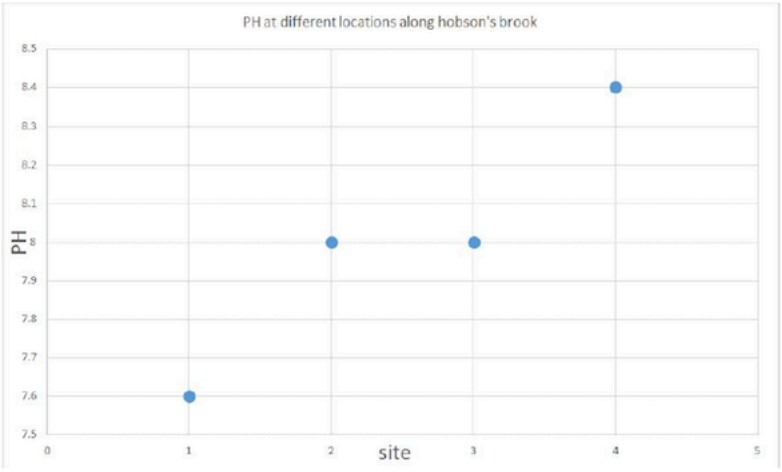
Further on in the river the banks widen and the bed deepens, resulting in more flow, but the speed slows down so in reality the amount of water passing a point per second doesn't change enough to support much more.

Water samples

Site Groups	1a	1b	2a	2b	3a	3b	4a	4b			
Site 1											
Air Temp °C	8.2		8.2		8.2		8.2				
Water Temp °C	11		7		9		11.5				
wind speed mph	0		0		0		0				
Flow rate mph	0.37	0.28	0.37	0.28	0.37	0.28	0.37	0.28			
Oxygen ppm	10		10		10		35				8-10= OK
pH	7.6		7.6		7.4		8				OK
Carbonate Hardness	20°d		15		15		250 ppm				high
General Hardness	8°d		16		8		250ppm				ok
Nitrite mg/l	0		0		0		0				
Nitrate mg/l	100		100		100		10				
Chloride mg/l	0		0		0		0				
Site 2											
Air Temp °C	7		7		7		7				
Water Temp °C	9.5		6				10.5				
wind speed mph	0		0		0		0				
Flow rate mph	0.28	0.38	0.28	0.38	0.28	0.38	0.28	0.38			
Oxygen	10		10		10		35				
pH	8		7.4		7.6		7				OK
Carbonate Hardness	15°d		20		15		250				
General Hardness	8°d		8		16		250				
Nitrite mg/l	0		0		0		0				safe
Nitrate mg/l	100		100		100		10				not safe
Chloride mg/l	0.8		0.8		0		0				
Site 3											
Air Temp °C	6		6		6		6				
Water Temp °C	9.5		6				10.5				
wind speed mph	0.2		0.2		0.2		0.2				
Flow rate mph	1.22.	1.19	1.22.	1.19	1.22.	1.19	1.22.	1.19			
Oxygen	10		8		10						
pH	8		7.6		7.6						
Carbonate Hardness	15°d		20		15						
General Hardness	8d		8		16						
Nitrite mg/l	0		0		0						
Nitrate mg/l	100		75		100						
Chloride mg/l	0.8		0.8		0						
Site 4											
Air Temp °C	5.8		5.8		5.8		5.8				
Water Temp °C	9.4		6				10.5				
wind speed	0		0		0		0				
Flow rate mph	0.14	0.12	0.14	0.12	0.14	0.12	0.14	0.12			
Oxygen	10		8		10		35				
pH	8.4		7.6		7.6		7				
Carbonate Hardness	20°d		20		20		250				
General Hardness	8°d		16		16		250				
Nitrite mg/l	0		0		0		0				
Nitrate mg/l	250		100		100		10				
Chloride mg/l	0.8		0		0		0				

With the water samples that we collected from different sections down the river we carried out a variety of tests.(At each section wee took 2 samples of water to measure)
These tests allowed us to measure the oxygen levels, ph, carbonate hardness, general hardness, nitrate, nitrite and chloride levels in the water. While at each section we also measured the air and water temperature, wind speed and flow rate.

Looking at the data we can see that as you get further away from ninewells the water temperature decreases. The water coming out of the spring is always around 10 or 11 degrees C. it loses the temperature when traveling down the river.



This is graph shows that as you get further down the river, away from ninewells, the PH of the water increases. The final recording took place near the allotments and the PH was highest. This is because the nitrates and chemical use there will be washed of the land and will end up in the water increasing its PH.

Biotic Assay

Site 1		Site 2		Site 3	
Name	Score	Name	Score	Name	Score
Cased caddis fly	7	Water shrimp	5	snail	1
Caseless caddis fly	5	Blood worm	1	Caseless caddis fly	5
Water mite	-	leeches	1		
worms	1	snail	1		
Water shrimp	5	Caseless caddis fly	5		
snail	1	Cased caddis fly	7		
leech	1	Midge larva	5		
Damselfly larva	10	Water beetle	5		
		Water mite	-		
		Mayfly larva	5		
		Stonefly larva	5		
CAST Score	4.29	CAST score	4.0	Cast Score	3.0
Quality	Very Good	Quality	Good	Quality	Poor

Overall we found that the quality of water decreased as we traveled from the source, downstream the river. This can be seen in the creatures that we collected. Each sample was given a quality rating, either very good, good, poor or very poor. The results to this can be seen above. These results are shown above and evidence that the quality of water is decreasing as you go downstream. We only went as far as the allotments though.

The water quality assessment was very simple to carry out. First we had to take samples at each location. Then when we got back to college we emptied the samples into trays and looked for all of the animals inside. When looking at what animals were present in each sample they were given scores. The higher the overall score was when they were all added together, the higher the sample scored. A higher score suggests a less polluted river ecology and therefore better quality and less polluted water.

The first sample was taken at the very source of the river, so was the cleanest. The next sample was taken just after the sluice. The 3rd sample was taken just outside the allotments and so had the highest concentration of nitrates, likely from the fertilisers.

The decrease in water quality downstream is likely due to the fact that the water hasn't been contaminated or polluted at the source as it has only just come out of the ground. However, further downstream the water is being polluted by all the planting, particularly near the allotments which is where the last sample was taken from. Due to all the plants growing and fertilisers which are used here the water is of a much lower quality as the fertilisers run off the plants and into the river when it rains.

Strategies being used to improve water quality

However, some action is being put into place to prevent this from happening. For example, farmers are being recommended to not use fertilisers at certain times of the year unless absolutely necessary, and the allotment users are also being told to restrict their use of fertilisers and only use non-toxic fertilisers so that even if they do get into the river they won't damage the ecology of the river. Additionally, another strategy being used is to start planting hedgerows to catch any toxic runoff before it reaches the river.

When scoring the sample we were limited on what we could identify as we didn't have the detailed books that get used by large companies who also BMWP Score system. Therefore we had to make our own system of scoring, by generalising what we had access to. Therefore the overall score that we got does not necessarily show what is actually present as it will be inaccurate.

When we did the abiotic survey we found that nitrate concentration increased as we went downstream. This would contaminate the river, resulting in lower quality water. This increase in nitrate is because of all the fertilisers that run down into the river.
Below are some of the pictures of the creatures that we found, a cased caddisfly, a bloodworm and a freshwater shrimp.

Water Management plan

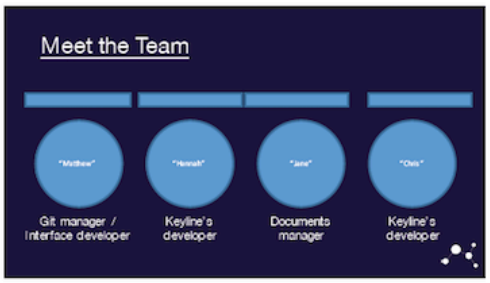
The end goal for the Conduit is to turn it into a healthy, diverse watercourse with appropriate Taccess and a range of riparian habitats supporting species, such as Kingfisher, Bullheads and water voles while also providing opportunities for local people to be actively involved with management of the site.

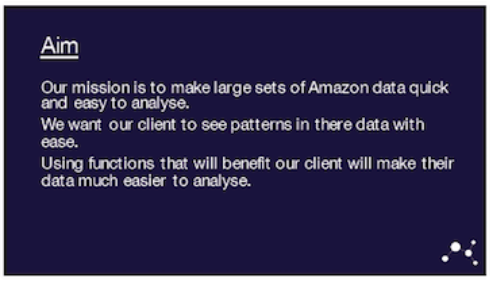
There are multiple methods that the surrounding water companies are planning to use to achieve this, the most prevalent to increase the water flow. One way of doing this is by pumping water from the Babraham site to the Nine Wells site, this would allow the flow rate

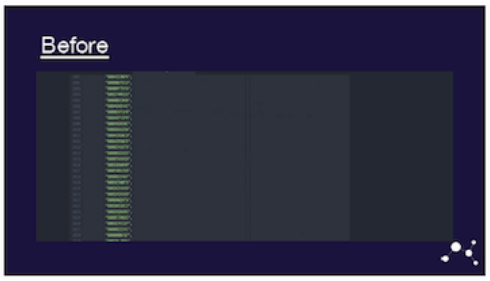
of the water. Another one of the solutions includes removing the current existing wells and replacing them with a new weir at the pools exit, this would help maintain water depth in

periods of low flow rate. By using machines the water companies want to re-establish the spring heads that the water flows up from by re digging them and restoring their natural shape and form. This will reduce silt coming from existing water channels ·

B.5 Slides from CS presentation delivered by Hannah and Jane on 18.05.23







Selling the Intelligence - Companies with products on Amazon

- Is a reviewer biased in a negative way to only their brand?
- What is the competition?
- How could we increase our revenue? By producing another product? Or taking one of the market?

Selling the Intelligence - Companies who don't have products on Amazon

- Is their a gap in the market?
- Is it worth selling their product on amazon?

"A picture is worth ten thousand words"

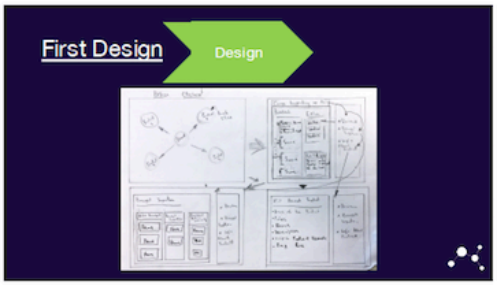
Fred R. Barnard

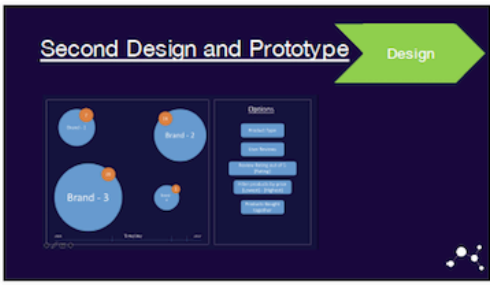
Timeline

Day 1 — Day 8

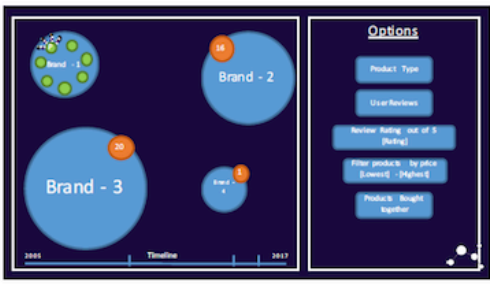
- Keylines Demos
- Learning JavaScript with the Keylines API
- Needs of the user
- Options

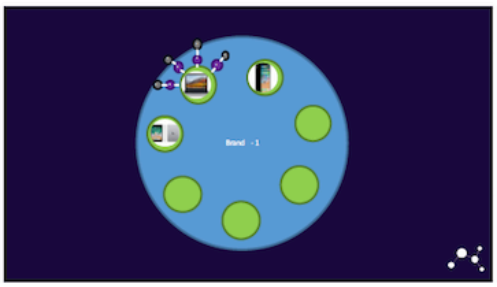
- Visual Prototype
- Deciding the features of our program
- Colour scheme

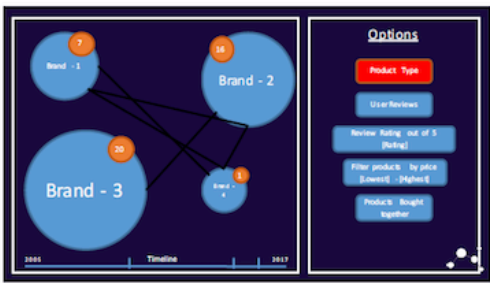

First Design
Design

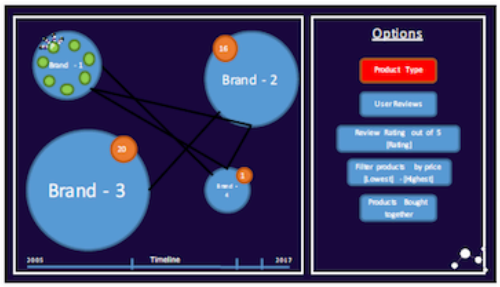

Second Design and Prototype
Design
Brand - 3
Options

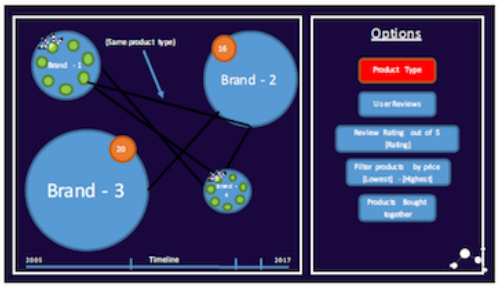

7
Brand - 1
16
Brand - 2
20
Brand - 3
1
Timeline
2005
2017
Options
Product Type
User Reviews
Review Rating out of 5 [Rating]
Filter products by price [Lowest] - [Highest]
Products Bought together

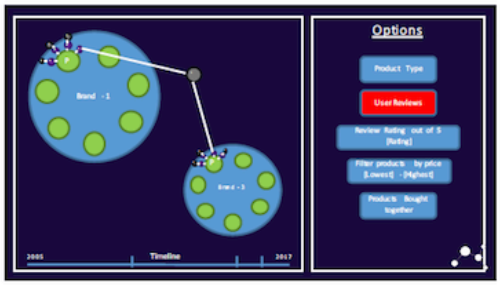

16
Brand - 2
20
Brand - 3
1
Timeline
2005
2017
Options
Product Type
User Reviews
Review Rating out of 5 [Rating]
Filter products by price [Lowest] - [Highest]
Products Bought together


Brand - 1


7
Brand - 1
16
Brand - 2
20
Brand - 3
1
Timeline
2005
2017
Options
Product Type
User Reviews
Review Rating out of 5 [Rating]
Filter products by price [Lowest] - [Highest]
Products Bought together







Features

Design

- Combos
- Option Buttons
- Search Bar
- Colour Coding Nodes
- Glyphs

Combos

- More compact.
- Easier to view the data as a whole.
- More aesthetically pleasing.
- It tidies up the data by grouping them into the same category.

Options

- Combine via brands:

Creates open combos with products inside, depending on the brands

- Combine via reviews:

Creates closed product combos, and when opened reveals the users that have reviewed it.

Search Bar

- Can find a certain product amongst loads of nodes.
- This can be useful for the client if they want to search for their product of the competitions. Which can save a lot of time.

Colour Coding Nodes

- Review nodes have a specialized colour halo depending on the overall rating of that review.

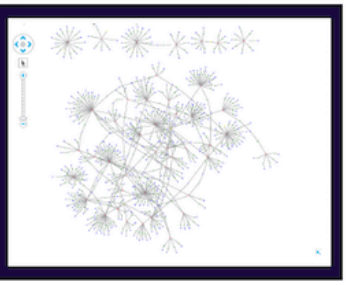
Colour of halo on node	Overall rating of product
Red	1-2
Yellow	3
Green	4-5

- Each type of data ie. Products, Product types or Reviewer nodes all have there own colour to help the client distinguish between them.

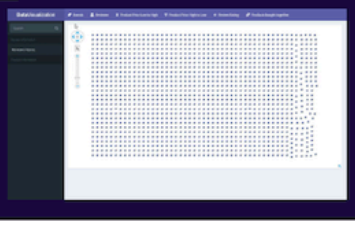
Glyphs

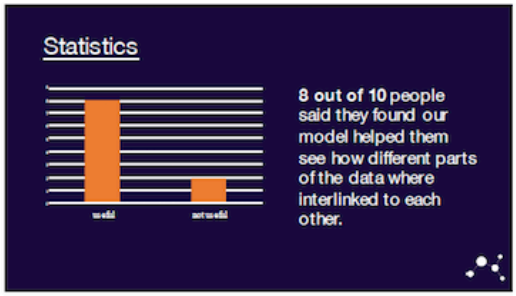
- On the combos to say how many nodes are inside the combo.
- On their reviews to identify how many people found the review helpful or unhelpful

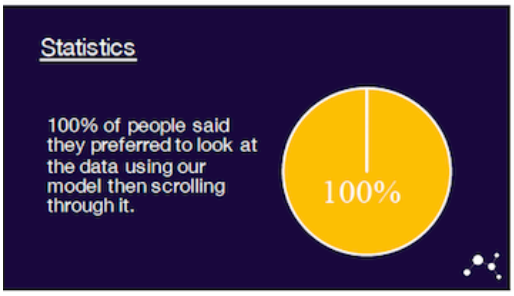
Before:

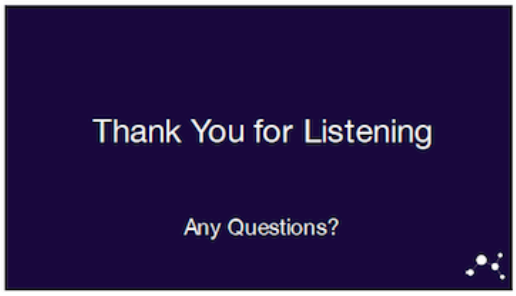


After

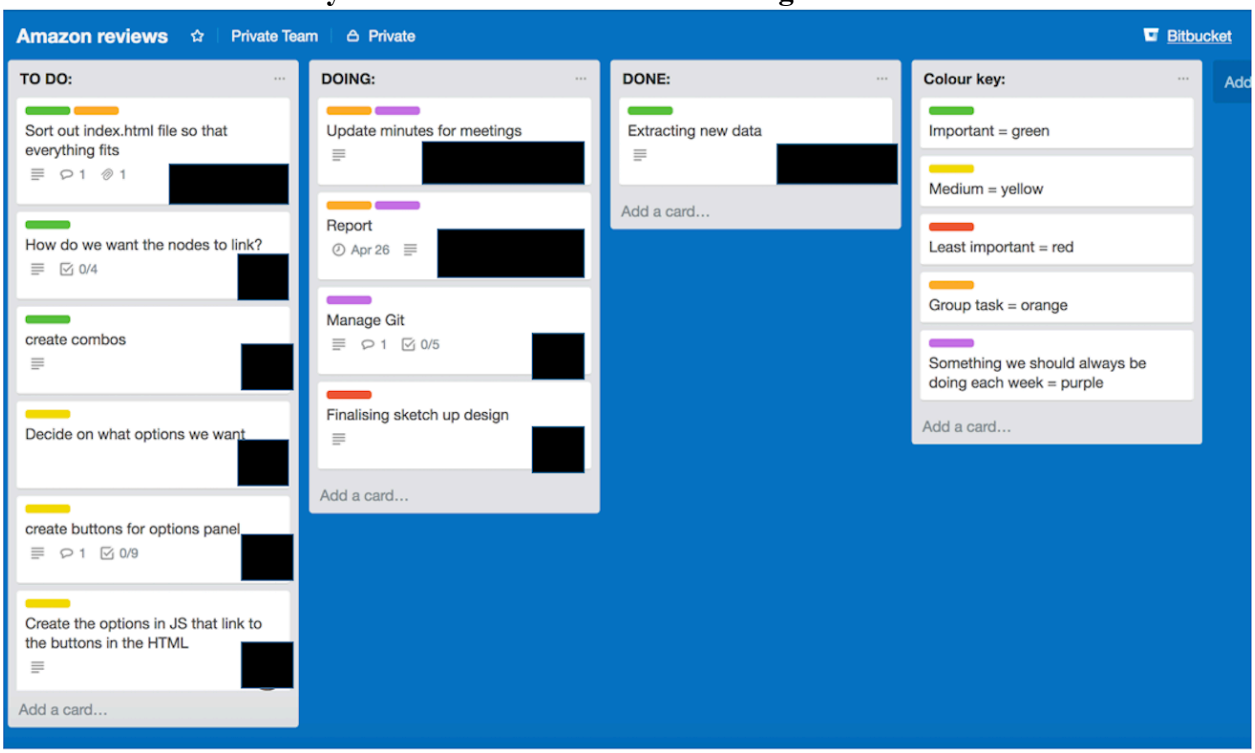








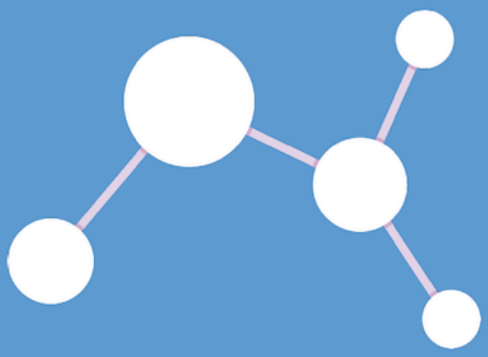
B.6 Trello board used by Hannah and Jane's team for organization with names redacted



B.7. Screenshots of report submitted by Hannah and Jane's group as part of the CS project

EDT arm Industrial Cadets

DATA VISUALIZERS REPORT



MATTHEW, HANNAH, JANE and CHRIS result for industrial cadets

CAMBRIDGE ACEDEMY FOR SCIENCE AND TECHNOLOGY Robinson Way, Cambridge, CB2 0SZ

Table of Contents

Abstract

Project Brief

Our aim is to organize the large data set in a way that allows the client to visualize what's going on within their data. We want to create links between the data, so the client can see how everything connects and affects each other. By using things such as colour coding, we can make it even easier to see 'bad' data and 'good' data, simply by changing the colour of a data node from red to green. With Cambridge Intelligence's toolkit, we used Keylines to achieve this.

Response

To do this we have to create a web page to display our data output. Therefore, we would need to know html and CSS/bootstrap. Also, the Keylines toolkit is written in JavaScript, so we would also have to learn that language too. Finally, we will need to design a visual prototype of our final product, this will help us develop our ideas and have a vision on what the end of our product will look like.

Research

HANNAH has previously done work experience with Cambridge Intelligence, so she already has some knowledge on Keylines. The rest of us had to start from scratch, by looking at the demos and API references.

With our research we found out how we want our final project to be and what options we want to involve in it via Keylines. We want to use combos, timelines, search bars, color coding and many more different effects.

Therefore, in Keylines we had to use the function in the API reference to do these options.

(e.g. **' chart. Combo().combine(Object. Values(map), {}, function () ')**

Source of data

R. He, J. McAuley

http://jmcauley.ucsd.edu/data/amazon/links.html

Research

To start with we used Khan Academy to help us understand how too code with JavaScript. This is useful because Keylines code with JavaScript and we must use their API references in HTML to create the network. Next, we looked at the Amazon data, we looked at how it was set out and Then we looked at the Keylines demos, source codes and API references of some of the demos to understand how it all works. Another part of our research was thinking about option that could be useful for the users. This required us coming together as a group and discussing what we have seen on the demos and thinking as the user. Another part of the research has been consulting with people from Cambridge Intelligence.

Research Outcomes

Data Layout

Another outcome of our research was deciding how we wanted the data to look when the HTML page was opened up. We decided as a group we wanted the data to be grouped in combos. A combo is when related nodes get group grouped together to make the data look organised.

Talking to Cambridge Intelligence

As a result of talking to Cambridge Intelligence We were able to then begin to create combos, however we were unsure on how to choose what data nodes we wanted to connect. So, when Cambridge Intelligence came in, we asked them how to reference the data in functions.

We had already started to attempt this prior their visit, and we weren't far off. All they did differently was split out our if statement into two and add some call backs within our functions.

Previously we were also exchanging emails with people from Cambridge intelligence to assist us with our coding.

Deciding Options

Looking at the demo options and data allowed us to think of options of our own that would be useful for the user. We talked about each option and how it helps, the options we finally decided on are listed below;

1. **Search Bar** - So the user can search for a product or a reviewer.
2. **Timeline** - The timeline at the bottom of the data allows the user to choose what reviews they would like to see between a certain time, this could allow them to filter out old reviews that could be viewed as not relevant.
3. **Product type** - Having the same product type as a filter it allows different companies to see who they are competing against.
4. **Reviewer** - Connect reviewers to all the reviews they have wrote and therefore connecting them to products they have bought. This could show if a reviewer is only being negative to one brand.
5. **Product rating** – Each product review has a rating for that product out of five. This option allows the user to choose what number rating they want to show.

6. **Products bought together** - The products bought together option is useful because If two different product types where bought together and one of the products brands doesn't produce the other product bought then they could manufacture that product type that would great more revenue for them.
7. **Highlighting node networks** – This option makes it easier for the user to see what nodes are connecting too, especially if the data is large and there are a lot of nodes.
8. **Review usefulness –** Every review has a like and dislike count. We will incorporate this into our details section in the options panel.

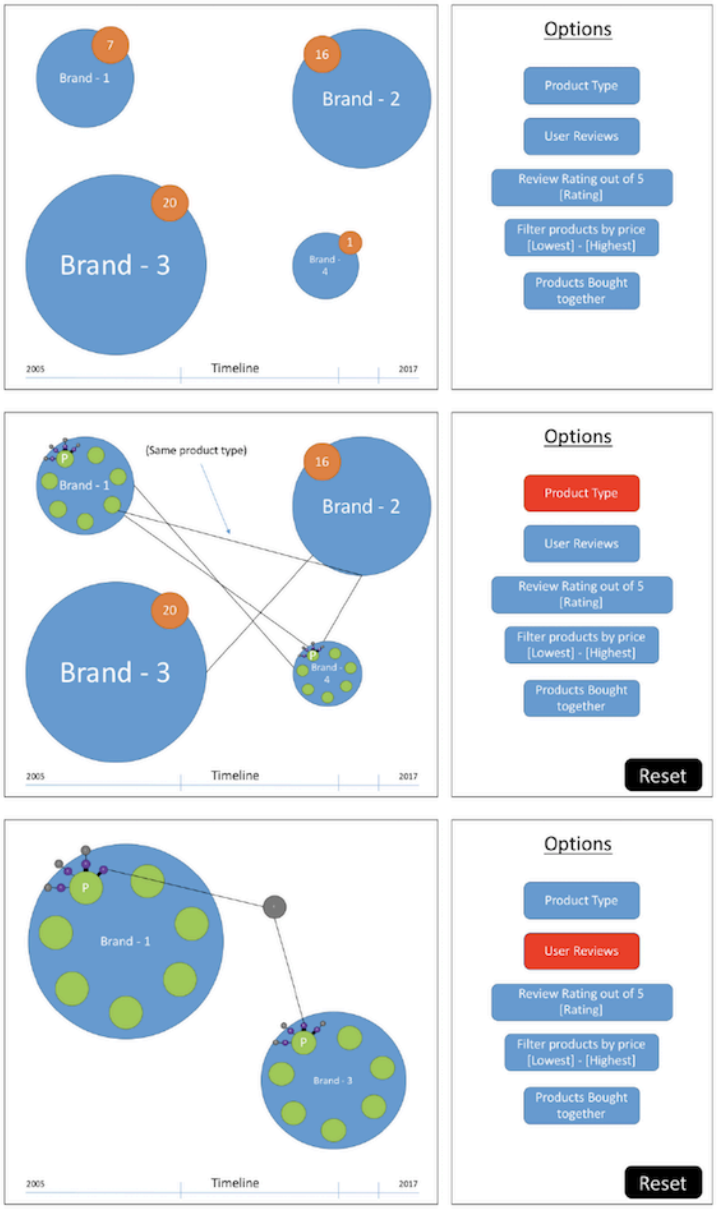
Visual Prototype

Figure 1: Visual Prototype

Our research also led us to create a visual prototype of what we wanted our design to look like. We created this from looking at the Keylines demos and seeing how they were laid out. We created the visual design in PowerPoint.

Having the visual prototype helped us decide on the design because in PowerPoint we could easily and quickly manipulate the design and change it to see what different layouts would look like.

In the end we decided on the design in figure 1. We wanted to go for a simple easy to read and use design. This is why we decided on the round nodes because they have curved edges and makes everything look smoother Compared to squares.



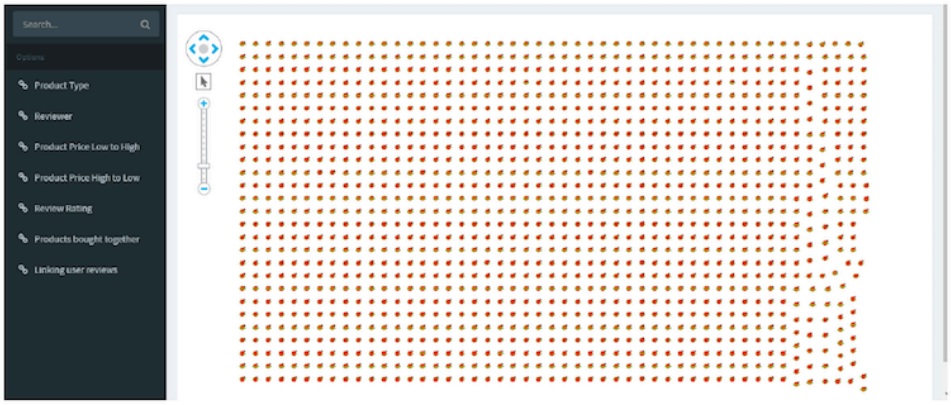
Method

Processing the Data

To start with we downloaded the data from the data source provided.

Layout of the HTML Page

Figure 2: Final html Layout



The visual prototype has helped us with the coding of the layout because we had an idea of what we needed to do to code the design. However, this did progress and develop to a completely different look for the html page. (As shown in figure 2)

Colour scheme

We chose a purple and grey colour scheme because we thought it gave the HTML page a professional aesthetic. This is important if you want different companies to buy the intelligence.

Buttons

With simple html and bootstrap code, we were able to create a professional look to our button features. We will then link them to functions once clicked on. These will then perform the instructions labeled on them, within our JavaScript code.

Search Bar

Within our bootstrap template, there was the layout for the search bar. It is essentially a text box with a search button attached. Within our code we will need to say;

'when this button is pressed, read what text is in the text box and do this function.'

We then link it to a function which will do a search over the data and highlight the product node they searched for.

Nodes

Node Layout

Within Keylines the nodes are presented on the screen as a default. We can manually place them within the code wherever we want, however the function for the node placement has a default option where it will place them wherever they fit.

Node Colour

- Brand

The brands will be yellow open combos, with the closed product combos inside.

- Product

The products will either have a picture of the product as the node or a blue colour, they will be a closed combo with the reviews inside.

- Review

The review will be colour coded based on its star reviews;

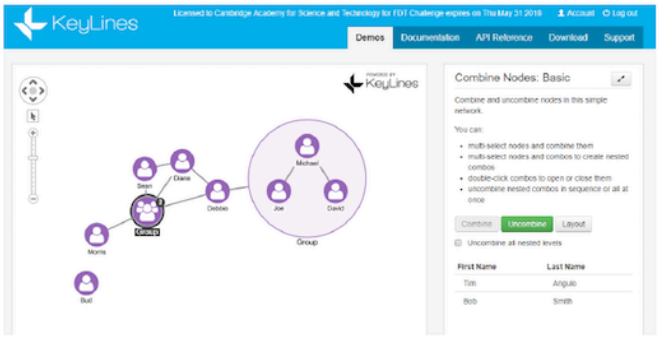
Colour	Overall rating 1-5
Green	4 and 5
Orange	3
Red	1 and 2

- Reviewer

The reviewer will either be connected to the review node in a purple colour, or once the review node is selected, the reviewers ID will be shown in the details section.

Combos

We will have 2 different sorts of combos, open and closed. As shown below, the closed combo is the node that has a glyph with the number of nodes inside attached to it. And the open combo is the one that already shows you the nodes inside.



Coding the Options

Search Bar

-The search bar will be linked to a function within our JS code that reads what was inputted in the text box and then searches for that product name through the data. It will then use chart.foreground function to highlight the searched item.

Timeline

-The timeline will filter through when the reviews were posted. It will also be linked to a function to say when they are currently on this date only show these reviews.

Product Type

-We may if we have time, add another combo function but this time by the user's choice, whether they have the products grouped by brands or categories, or both

Reviewer

-When a review node is selected we will then run a function that searches the data for the reviewer and prints its ID to the details section.

Review rating

-As with the reviewer, once the review is selected it will run a function that will search for likes and dislikes that review has and show it on the details panel.

Linking user reviews

-A final option we are doing is that the user can click a button that will link reviews if they are by the same reviewer.

Problems Encountered

Large Data Set

Firstly, one of our computers wasn't fast or powerful enough to download a large amount of data, so we had to see whose computer would be able to handle it. Our second problem was it took a long time to download the data, so we did a bit at a time. We wanted different categories as well, so we had to download even more. Our webpage unfortunately now loads slowly due to all the data its having to read. We could not make the loading of the data any faster however as a half solution we are using a smaller amount of data for testing instead of the large set.

Combos

We knew the code to be able to perform the combos, however we didn't know how to refer to the data we wanted to combine. The layout of the data wasn't how Jazmin was used to when she did work experience there, as she worked with a much smaller sample. We then realized that we were only able to view the raw data, and that the code in the app.js file was what transformed the code to a more Keylines friendly way. But, we couldn't see that output of this as it was displayed straight to the webpage and not to another document. When Cambridge intelligence came in to visit us, they showed us to tell the code what nodes we wanted to combine.

To do this you had to make an empty object. Then iterate through all the nodes. Then there was an if statement saying; if this node is a review do this next if statement, if not move on to the next node. If the node was a review then there was another if statement saying, if this reviews asin id isn't already in the object then add it to the object and add the review id to the asin array.

This then formatted all out different product groups, with all the reviews in an array next to that product.

Results

Our final product meets the needs of the user allowing them to use different options to organize the data. Even though we are using a large amount of data and it is quite slow at loading, it still looks professional.

Marketing

Businesses/Companies can use this toolkit to organize their data in a way that benefits them. Visualizing your data allows you to detect faults within the business much quicker. Also, the data is much nicer to look at.

This is also a reliable way to do it, as no data is left out as the functions in our code iterates (looks through) all data sets, then does the following command to it.

Our user interface is also very easy to use and navigate through the data. So, anyone can use this to observe their data.

Accuracy and Reliability of the data

We know our data is accurate because for all our code, we drag the data straight out of the amazon data set so that we don't code any of it. We also tested it to make sure the nodes link up to the right nodes.

Selling the Intelligence

We are marketing our product to companies that are selling their products on amazon or are thinking of selling their items on amazon.

For companies thinking of adding their product to amazon with our tool, they could easily see if there is a product type that only has bad reviews for every brand that produces that product, by filtering the data by the same product type you could then look at the review nodes and if they are red around each product. This could then be viewed as a good business opportunity for the company that produces that product type and doesn't have it on amazon already.

If a Company sells their product on amazon and it is being bought a lot with another product that they don't produce it they could invest in producing that product and then sell it.

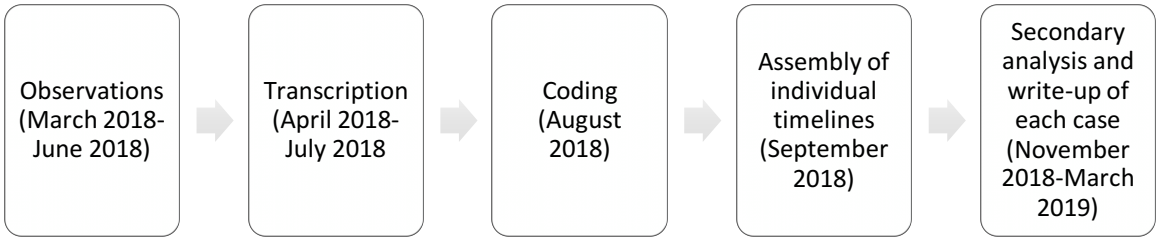
Conclusion

Overall, we have learnt much during this challenge project. Not only have we developed out coding skills, but we have also learnt a new language, how to deal with large data sources and how to organize them.

As a team we have developed as well. When we run into a problem we all work together to solve it. Each week we would have an AM and PM meetings to sort what we were doing that day and how we think the day went. This really brought us together as a group and made problems easier to tackle.

APPENDIX C-TOOLS USED FOR ANALYSIS

C1. Updated timeline of major events in the data collection and analysis process



C2. Tables of codes derived from the emergent coding phase; used to identify data of primary interest based on themes

C.2.a Code table for the CS project (Hannah and Jane)

Content Knowledge	Motivation	Procedural Knowledge	Transferrable Skills
Consumer focus	Disengaged	Analysis of code	Communication
Output data interpretation	Engaged	Analysis of product	Perseverance
Programming conception-accepted	External motivation	Decision-making	Planning (transferrable)
Programming conception-unaccepted	Internal motivation	Knowledge of syntax	Problem-solving
Programming logic	Negative self-efficacy	Logic	Self-management
Role of programming (in society)	Positive self-efficacy	Planning (procedural)	Teamwork
Rules of programming			
Source data interpretation			

C.2.b Code table for the Water Management project (Hamish)

Conceptions	Content Knowledge	Motivation	Procedural Knowledge	Transferrable Skills
Accepted	Biodiversity	Engagement (neg)	Analysis	Communication
Contradiction	Competition	Engagement (pos)	Explain	Perseverance
Incomplete	Conservation	Motivation (ext)	Observation	Planning (transferrable)
Misconception	Management	Motivation (int)	Planning (procedural)	Research
Vague	Nature of science	Perception (neg)	Reporting	
	Neglect	Perception (pos)		
	Pollution	Self-efficacy (neg)		
	Water	Self-efficacy (pos)		
	Wildlife	Self-esteem (neg)		
		Self-esteem (pos)		

APPENDIX D-FORMS AND LEGAL DOCUMENTS

D.1 School day format at Cambridge Academy for Science and Technology (CAST). Retrieved from https://cast.education/college-life/students-and-families/college-day

College Day

8:30 – 8:45	Tutor Time
8:45 – 9:35	Lesson 1
9:35 – 10:25	Lesson 2
10:25 – 10:45	Break
10:45 – 11:35	Lesson 3
11:35 – 12:25	Lesson 4
12:25 – 1:15	Lesson 5 (KS4 Lunch)
1:15 – 2:05	Lesson 5 (KS5 Lunch)
2:05 – 2:55	Lesson 6
2:55 – 3:45	Lesson 7
3:45 – 4:35	Lesson 8 (Tuesday)
3:45 – 4:35	Supervised Study (Monday, Thursday & Friday)
3:45 – 4:35	Extra Curricular (Wednesday)

D2. Consent for offered to students interested in participating in the research[53]

UNIVERSITY OF CAMBRIDGE
Faculty of Education

Jessica Dobrin
PhD Student , Faculty of Education

Dear Students and Parents/Guardians,

Please allow me to introduce myself. My name is Jessica Dobrin, and I am a student at the University of Cambridge, currently finishing my second year as a PhD student in the Faculty of Education. My research looks at how students develop conceptions in science during project work, much like the Challenge Projects here at UTC. The goal is not to compare one student to another, but to see how each unique individual uses these projects to help themselves learn. I will be in throughout the year observing and speaking with several students as part of this research, so I wanted to take some time to answer a few questions that may be of interest to you.

-This work and any observations I make will NOT affect your marks or your standing in any course. Any and all responses are made anonymous, and will only be shared with the school as part of general findings.
-You are not required to be an active participant, and even if you volunteer, you can opt out at any time for any reason. This is meant to help me but also to help you, and if you do not feel this is the case, let me know and we can work to either fix the problem, or you may leave the study.
-The time commitment will be approximately 2 short (15-20 minute) interviews per week during your Challenge Projects. In order to maximise your time, it is perfectly okay to use me as a resource for bouncing ideas off of during these sessions. Talking out my ideas has always been a help to me.
-While I plan to record interview sessions and transcribe responses, these are absolutely anonymous, and no non-researcher will ever hear the audio. Any bits of the transcript I use in the published research will be printed with your approval. You may also ask that certain responses not be used at all. Again, you may change your mind at any time.
- If I am in doubt, I will always verify with you what has been said. I want this project to be as authentic as possible, and I want you to be in control of your communication.
-Finally, please do try to enjoy this process. It is meant to be a mutually beneficial endeavour, and please feel free to be yourself in all of our meetings.
-If you do not want to be included, even in the classroom observations, please use the opt-out section below. If you do not return this form, it will be assumed that you agree to participate in the classroom observations. The interviews must be opt-in.

(please check one. If you do not want to participate but are okay being part of general observation, please just do not return the form)
__ I consent to being a full participant in this research. I understand that I may change my mind at any time
__ I do NOT consent to data being collected from me in classroom observations. I understand that I may change my mind at any time and opt-in

_____	_____	_____	_____
Student Name	Student Signature	Guardian Name	Guardian Signature

If you have any further questions, please email me at pblresearch@parksidefederation.org.uk
Thank you,
Jessica Dobrin
PhD Student
STEM Education Group, Faculty of Education
University of Cambridge

The Old Schools
Cambridge CB2 3PU

Tel: +44 (0) 1223 339396
Fax: +44 (0) 1223 764062

www.cam.ac.uk

[53] As a note, several students received an older version of the form that included (1st year probationary) based on when they volunteered. No changes to the agreement were made

APPENDIX E-GLOSSARY OF COMPUTER SCIENCE TERMS[54]

API reference-API, or application programming interface, is a set of functions that can be used to build software. The API reference is essentially instructions on how to best use a specific API

ASIN- an ancronym that stands for Amazon standard identification number. It is a 10-digit code that can be used to identify a unique project. Generated by Amazon, except for books where the number is the same as the ISBN

Big data- an extremely large volume of data that is generally too complex to be analysed by traditional data processing software.

Call (the data)- identify or load target data; in this project it is acceptable to use this interchangeably with reference (the data)

Debugging-the process of reading through code to fix errors or remove unnecessary and/or non-functioning code

Demos-Short for demonstration, these are examples of KeyLines features, along with the source code segments necessary to create that feature

Git- a tool that can be used to track changes in source code. Many different code sharing websites such as bitbucket.com (used by the team) work in conjunction with Git

Parser-A program for formatting data into a formal structure

Reference (the data)- identify or load target data; in this project it is acceptable to use this interchangeably with call (the data)

[54] Terms in this glossary are based on personal communications with Cangea, C., a computer scientist at the University of Cambridge