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The other art of computer programming: A visual alternative to communicate computational thinking

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The Other Art of Computer Programming

A Visual Alternative to Communicate
Computational Thinking

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Declaration of Authorship

I, Melanie Tarr, declare that this thesis titled, “The Other Art of Computer Programming” and the work presented in it are my own. I confirm that:

- This work was done wholly or mainly while in candidature for a research degree at this University.
- Where any part of this thesis has previously been submitted for a degree or any other qualification at this University or any other institution, this has been clearly stated.
- Where I have consulted the published work of others, this is always clearly attributed.
- Where I have quoted from the work of others, the source is always given. With the exception of such quotations, this thesis is entirely my own work.
- I have acknowledged all main sources of help.
- Where the thesis is based on work done by myself jointly with others, I have made clear exactly what was done by others and what I have contributed myself.

Signed: [redacted]

Date: 20th January 2020

Abstract

The thesis will explore the implications of teaching computer science through visual communication. This study aims to define a framework for using pictures within learning computer science. Visual communication materials for teaching computer science were created and tested with Year 8 students. Along with a recent commercial and political focus on the introduction of coding to adolescents, it appears that the computer industry has a large shortfall of programmers. Accompanying this shortfall is a rise among adolescents in the preference for visual communication (Brumberger, 2011; Coats, 2006; Oblinger et al., 2005; Prensky, 2001; Tapscott, 1998) while textual communication currently dominates the teaching materials in the computing discipline. This study looks at the learning process and utilises the ideas of Gibson, Dewey and Piaget to consider the role of visual design in teaching programming. According to Piagetian theory Year 8 is the time a child begins to understand abstract thought. This research investigated through co-creation and prototyping how to creatively support cognition within the learning process. Visual communication theories, comprising the fields of graphic and information design, were employed to communicate computer science to approximately 60 junior high school students across eight schools. Literature in a range of visual communication fields is reviewed along with the psychology of perception and cognition to help create a prototype lesson plan for the target audience of Year 8 students. The history of computer science is reviewed to illustrate the mental imagery within the discipline and also to explore computational thinking concepts. These concepts are "... the metaphors and structures that underlie all areas of science and engineering" (Guzdial, 2008). The participants' attitudes increased toward learning programming through visual communication. Quantitative questionnaires were used to gather data on cognition and measure the effectiveness of the learning process. Thirteen hypotheses were established concerning learning programming through pictures from the quantitative data. Focus groups further triangulated data gathered in the quantitative stage. Approximately seventy percent of the participants understood seventy percent of the information within the instrumentation. Models of intent to learn programming through pictures were established using structural equation modelling (SEM). Outcomes of the exegesis are a framework for using pictures that demonstrates computational thinking and explains the research.

Acknowledgements

A PhD is an arduous and solitary process. Firstly I would like to thank my main supervisor Associate Professor Stuart Medley for your time and dedication throughout this process. Thank you also to Dr Greg Baatard my associate supervisor. To my long suffering husband, Chris Tarr who has a very busy career of his own, I will never do this again and thank you for reminding me that this is not my life. To my children Lilybelle and Jai, you are my biggest achievements.

Further thanks go to the participants that took part in my research. Also to then Deputy Vice Chancellor Robyn Quin who foresaw a vision and supplied a grant to start the first high school iOS group in a low socio-economic school. To Everal Eaton, Sheldon Smith, Dr David McMeekin, Professor Moses Tade, Professor Shelley Yeo, Dr Graham Mcmahon, Ben Beaton, Catherine Shepherd, Jan Stone, Dr Lyndall Adams, Dr Jo McFarlane and Dr Kylie Stevenson, thank you.

Also thank you to Dr Doron Swade and Professor Don Knuth for their correspondence, especially since the latter stopped emailing in the 1990s. To Dr David Goodall for helping me finish my first draft and his daughter Karen. My father was taken by his dad as a five year old on weekends to watch the first flat roof house being built (Harry Seidler's) in Australia. So thank you Dad for telling me about that situation and "if everyone did things the same, nothing would ever be different".

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This work is dedicated to my
grandfather Joseph Knight-Smith
(sign-writer) and his teacher and
uncle, Edward M Smith, lecturer in
drawing East Sydney Technical
College, 1920s - 40s.

Glossary

Aesthetic Used in this study as a dependent variable that adds value to whoever sees it. It can represent a style of presentation or have semiotic meaning or cognitive meaning behind it. For the purposes of this study it is associated with the pictures in the lessons and is equivalent to visual aesthetic. It is a variable to be constructed into the treatment that will be created in Phase One of the research plan. xx, 18, 85, 110, 273

Animation A dynamic representation where the information about temporal change is contained in the difference of object properties between successive frames" (Lowe, 2008; R. Lowe Schnotz, 2008). xx, 46

Avatar To make one's appearance or the embodiment of essence in another form Kare (1986). Within TOAOCP an avatar is a digital picture that is a human silhouette used in the interface and interaction design. xx, 181

Bartlett's test of sphericity Statistical test for the overall significance of all correlations within a correlation matrix" (Hair 2006, p. 102). xx, 191

Braiding The elements in sequence (usually pictorial) for the reader of a comic. Braiding is closely related to narrative. xx, 200

Coding The implementation of the solution to a problem with a programming language. xx, 27, 29, 31

Cognition Cognitive activity within TOAOCP is essentially concerned with meaning (Ortony, Norman, Revelle, 2005) and is measured by two factors Self-Assessed Cognition and Actual Cognition (AC). Actual Cognition (AC) concerned the participants understanding of the visual programming concepts within the instrumentation. A knowledge test measured AC. Self-Assessed Cognition is the factor representing the participant's own assessment of their understanding of a computer programming concept communicated through a picture or comic. xx, 26, 46–48, 50, 60, 68, 69, 78, 80–84, 103

Cognitive architecture The way the brain organises itself with respect to cognition or understanding. This is highly connected with visual based instructional design. xx, 96

Cognitive load Understands that presenting information in multiple ways is harmful for the brain. For example, If we have to coordinate lesson navigation learning is depressed. Also see split-attention effect. xx, 30, 41, 71, 81, 106, 159, 162

Computation A mathematical object made up of questions that computers solve. xx, 71, 87, 109, 132

Computational thinking Strategies that enable students to transform complex problems into multiple steps or procedures that can be ordered and are computable. xx, 5, 6, 12

Computer programming The process that defines a problem and then progresses through to running an executable computer program that solves the original problem. This process is one of the stages of the software development process. xx

Computer science The study of automating algorithmic processes that can be scaled upwards or downwards depending on the size of a problem. The computer science discipline combines the theory of computation as well as the design of its systems. xx, 23, 27–29, 31, 51, 60, 64, 69, 87, 96, 108, 109, 111, 113–118, 122, 123, 126, 129, 132, 149, 157, 159, 162, 324, 326

Construct A term used in structural equation modelling instead of factor. Constructs help explain the components of theories and vary in complexity. xx, 192

Construct validity The degree that a test measures what it says it is measuring. Construct validity encompasses both convergent and discriminant validity. xx, 192, 241

Convergent validity The degree that two measures that should be related. xx, 227, 241

Correlation These can indicate a predictive relationship and is any broad class of statistical relationship where one variable depends upon another. The two variables are linearly related. xx, 227

Correlation matrix "Table showing the inter-correlations among all variables" (Hair, 2006, p. 102). xx

Cronbach's alpha "Measure of reliability that ranges from 0 to 1, with values of .60 to .70 deemed the lower limit of acceptability" (Hair, 2006, p. 102). xx

Cross-loading "A variable has two more factor loadings exceeding the threshold value deemed necessary for inclusion in the factor interpretation process" (Hair, 2006, p. 102). ix, xx, 190, 366

Dependent variable These variables represent the outcome that is being studied within the quantitative analysis of TOAOCP (see Chapter 6, Table 5.4). Self-Assessed Motivation, Self-Assessed Cognition and Intent to learn are examples of dependent variables within TOAOCP. xx, 226, 232

Diagram Diagrams are information graphics that are made up primarily of geometric shapes such as rectangles, circles, diamonds, or triangles. Lines or arrows sometimes interconnect these shapes. Two major purposes of a diagram is to show how things, people, ideas activities, etc., interrelate and interconnect. Unlike charts and graphs, diagrams are used to show interrelationships in a qualitative way. xx, 24, 27, 63, 66, 67, 69–71, 73–75, 82, 105, 108, 109, 112, 113, 117, 118, 121, 138, 157

Discriminant validity Also known as the divergent validity. Tests whether concepts or measurements that are unrelated are unrelated. xx, 191

Eigenvalue "Column sum of squared loadings for a factor; also referred to as the latent root. It represents the amount of variance accounted for by a factor" (Hair, 2006, p. 102). xx, 190

Extraneous processing Situations that need heavy amounts of cognition or high comprehension and are complex. xx, 140

Factor "Linear combination (variate) of the original variables. Factors also represent the underlying dimensions (constructs) that summarize or account for the original set of observed variables" (Hair, 2006, p. 102). Also known as latent variable or independent variable. xx, 256

Factor loadings "Correlation between the original variables and the factors, and the key to understanding the nature of a particular factor. Squared factor loadings indicate what percentage of the variance in an original variable is explained by a factor" (Hair et al., 2006, p. 102). xx

Factor matrix "Table displaying the factor loadings of all variables on each factor" (Hair et al., 2006, p. 102). xx

Factor pattern matrix "One of two factor matrices found in an oblique rotation that is most comparable to the factor matrix in an orthogonal rotation" (Hair et al., 2006, p. 102). xx, 245

Factor rotation "Process of manipulation or adjusting the factor axes to achieve a simpler and pragmatically more meaningful factor solution" (Hair et al., 2006, p. 102). xx, 217

First order factor Examples of first order factors within TOAOCP were usefulness and fear. These factors are derived from the observed variables or items. xx, 238

Flowchart A flowchart is a type of diagram that can represent an algorithm or data flow used across disciplines and not restricted to computer science. Boxes of different shapes or polygons represent processing steps. Shapes represent each step connected by arrows. The direction of the arrows indicates the processing order. Flowcharts are a diagrammatic representation of a solution to a problem. xx

Formative The measured variables of a formative statistical model are the cause of the latent variable. For example, the factor of fun influenced the intent to learn programming through pictures. xx, 191

Goals of learning This may not always be education, entertainment, knowledge acquisition or enjoyment. Different disciplines will have a different focus for learning on this. For education it is knowledge acquisition, for design it is joy, etc . xx

Graphicacy "The ability to understand, use or generate graphic images" (Merriam-Webster, 2015). xx

Icon A navigation tool on a computer screen in the form of a pictogram or ideogram. The user navigates a computer system through icons. "The icon itself is a quickly comprehensible symbol of a software tool, function, or a data file, accessible on the system and is more like a traffic sign than a detailed illustration of the actual entity it represents" (Rosenblatt, 2012). xx

Image An image is a visual representation of something. This can either be mental or seen with the eye. An image can be copied and can transcend media. xx

Inclusivity Mostly concerned with universal design and learning that includes the most people as possible or the widest audience as possible. xx

Independent variable These variables represent the causes of the dependent variables. For example, the amount of pictures used in a programming curriculum may influence a student's intent to learn computer programming. The independent variable here is the amount of pictures. xx

Instructional text A text or dialog mostly concerning instructions. xx, 41

Kruskal-Wallis test A non-parametric statistical measure of whether more than two independent groups differ. xx, 227

Latent construct These are theoretical in nature and cannot be observed directly. For example, the factor of Intent is latent. vii, xx, 190, 193

Latex Is a mark up language specially suited for scientific documents. xx

Learning comic The instrumentation developed for this research was a unique comic that focused upon the transfer of technical information to a learner primarily through pictures. The comic has been created by a graphic designer and aligns with the principles of Gestalt and visual perception. xx

Linear regression A commonly used type of predictive analysis. The regression explains a relationship with one dependent variable to another independent variable. xx, 185, 186, 194, 231, 258

Little's test This test checks that data is missing completely at random (MCAR). It satisfies there are no patterns in the missing data. xx

Mathematics Mathematics is what mathematicians do. xx

Mental model Reasoning whereby the world is a simulation outlined by an individual's knowledge. Mental models are iconic and concern the ideals of Peircean logic. The mental model corresponds to the way the brain organises what it is or represents (Peirce, 1931–1958). xx, 41, 78, 87, 96, 104, 160

Multi-modal Study involved with learning and the representations of modes on a digital screen. This is concerned with communication and how this is transferred in these modes through learning. It is mostly used in the discourse of online learning. xx, 117

Multicollinearity "Extent to which a variable can be explained by the other variables in the analysis" (Hair et al., 2006, p. 103). Reflective and formative constructs are also examined through multicollinearity. xx, 191, 226

Multivariate This means many variables and often used when there is more than one outcome variable (Field, 2013a, p. 90). xx, 189, 195

Neuroaesthetic "A new field of research emerging at the intersection of psychological aesthetics, neuroscience and human evolution." (Visual neuroaesthetics is characterised by Zeki and Ramachandran's theoretical perspectives). The framework constructed within this research sees aesthetic experience (neuroaesthetics) as the embodied process of meaning-making and aligns itself with Dewey's perspective. This is different to aesthetic significance that is a variable in this thesis defined in the instrumentation. xx, 90

Neuroaesthetics see neuroaesthetic. xx

P-value This value is the probability of finding the observed results when the null hypothesis of a study is true. xx, 191, 195, 216, 238

Picture A picture is an artefact or record that contains sensory information for representations such as environments, objects, concepts as well as others for the eye to use. There is an important difference in some academic literature between the definition of a picture and the definition of an image. According to W J T Mitchell, "... you can hang a picture, but you can't hang an image" (Asbjørn & Øyvind, 2006, p. 16). xx

Pragmatic research A mix of different approaches to research to maximise triangulation. xx, 150

Principal component analysis A technique used to bring out strong patterns in a data set. Field (2013a) defines this technique as "A multivariate technique for identifying the linear components of a set of variables" (p. 792). xx, 178

Reflective Here the indicators of a construct are caused by that construct. For example within TOAOCP cognition would cause usefulness to occur, which did not actually happen within the model as both SEM models for comics and pictures were formative. xx, 191, 193

Reliability "Extent to which a variable or set of variables is consistent in what it is intended to measure. If multiple measurements are taken, reliable measures will all be consistent in their values. It differs from validity in that it does not relate to what should be measured, but instead to how it is measured" (Hair, 2006, p. 103). xx, 176–178, 192

Reverse scored "Process of reversing the scores of a variable, while retaining the distributional characteristics, to change the relationships (correlations) between two variables" (Hair et al., 2006, p. 103). xx, 218

Rotation A process in factor analysis for improving the interpretability of factors. In essence, an attempt is made to transform the factors that emerge from the analysis in such a way as to maximise factors loadings (Field, 2013a, p. 793). xx, 190

Schema "...a cohesive, repeatable action sequence possessing component actions that are tightly interconnected and governed by a core meaning" (Piaget & Cook, 1952, p. 419). xx

Schema theory The basis of modern cognitive theory (Gick & Holyoak, 1980, 1983). All knowledge is organised and elemental. Connected to Jean Piaget's cognitive model. xx

Scree plot "... a graph plotting each factor in a factor analysis (X-axis) against its associated eigenvalue (Y-axis). It shows the relative importance of each factor. This graph has a very characteristic shape (there is a sharp descent in the curve followed by a tailing off) and the point of inflexion of this curve is often used as a means of extraction" (Monier-Williams, 1923; Sheth, 2002). xx

Self-efficacy One's confidence in personal ability to undertake a certain task or behaviour. This definition is according to Albert Bandura's self-efficacy theory. xx

Single factor rotation Within TOAOCP this was a process whereby all factors were loaded into a single construct to satisfy Harman's score. This was used with principle component analysis. xx

Sphericity A less restrictive form of compound symmetry which assumes that the variances of the differences between data taken from the same participant are equal (Field, 2013b, p. 794). xx

Split-half reliability A measure of reliability obtained by splitting items on a measure into two halves and obtaining a score from each half of the scale. This is used as a measure of reliability (Field, 2013b, p. 794). xx

Spraction Used in philosophy and psychology first used by Barbara Tversky. Was invented on the premise that since we exist in space then we make sense of things or understand them through space. For example, the information here can concern shapes, entities and their relationships, arrows, dashes and locations that are combined to help the brain construct meaning between objects and frames of reference (Tversky, 2014). xx

State diagram A diagram used to represent the behaviour of a system. A state diagram contains a number of states that represent an entire system. The state diagram also contains the transitions between these states. These diagrams represent the meaning of the words and not the syntax of the code. xx

Structure matrix "A factor matrix found in an oblique rotation that represents the simple correlations between variables and factors, incorporating the unique variance and the correlations between factors. Most researchers prefer to use the factor pattern matrix when interpreting an oblique solution" (Hair et al., 2006, p. 103). xx, 256

Topology This concept concerns the arrangement of the parts of a diagram. The way the creator of a diagram organises the constituent elements or parts is called the topology. xx, 56, 70, 109, 110

Universality Associated with being universal or widespread. xx

Validity "Extent to which a measure or set of measure(s) correctly represents the concept of study – the degree to which it is free from any systematic or non-random error. Validity is concerned with how well the concept is defined by the measure(s) whereas reliability relates to the consistency of the measure(s)" (Hair, 2006, p. 104) Evidence that a study allows correct inferences about the question it was aimed to answer or that a test measures what it set out to measure conceptually. xx, 137, 163, 176, 177, 187, 190, 192

Variate "Extent to which a measure or set of measures correctly represents the concept of study – the degree to which it is free from any systematic or non-random error. Validity is concerned with how well the c oncept is defined by the measure(s), whereas reliability relates to the consistency of the measure(s)" (Hair et al., 2006, p. 104). xx

VARIMAX "The most popular orthogonal factor rotation methods focusing on simplifying the columns in a factor matrix. Generally considered superior to other orthogonal factor rotation methods in achieving a simplified factor structure" (Hair et al., 2006, p. 104). xx

Visio-spatial Relating to or denoting the visual perception of the spatial relationships of objects. These skills enable us to recognise shapes. xx, 84

Visual communication The conveyance of ideas and information in forms that can be read or looked upon. Visual communication in part or whole relies on vision, and is primarily presented or expressed with two-dimensional images. Visual communication is typically embodied in signs, typography, drawing, graphic design, illustration (Sless, 1981). xx, 139, 141, 143, 146, 147, 149, 157, 160

Visual perception In this study is the ability to interpret visual stimulus, or make meaning of what a person sees. It is perception during learning activity while viewing pictures that this Thesis is concerned with. xx, 26, 38, 39, 55, 79, 95–97, 101

Visuals A form of media in which information is presented visually; text may not be considered a visual form. xx, 104

Working memory Or short-term memory is the change from holding to cognition. It's limited and is short. If information is well learnt it doesn't suffer from the limitations. This consists of multiple streams, channels and processors (Baddeley, 1992; Baddeley, 1974). xx

Chapter 1

Introduction

Historically, there have been a number of technical milestones in the field of modern computer programming (Brumberger, 2011). Currently, education about these milestones does not routinely occur within junior high school. Textbook education within computer programming is dominated by text. The role of visual communication is undefined and under-explored within current programming practice. Despite this lack of definition, the role of pictures in learning science is the current focus of much academic debate (Hoffmann & Wittmann, 2009).

1.1 How this research began

I have always been concerned with how things look. In 2012 while employed as a programmer in an engineering department at a large university, I shared an office with an outreach coordinator. The coordinator had been employed in some of the most challenging schools in South Africa and specialised in getting refugees and other members of marginalised communities into engineering degrees. At the same time, I had begun looking at application development for mobile phones and had begun to showcase app development in 2011 (see Figure 1.1). After attending courses in Melbourne on these programming languages, a colleague and I realised they had become almost (and I use a vernacular term here) idiot proof. For example, an application using MapKit technology with full location services was taking under 30 seconds to program.

FIGURE 1.1: App development coding demo, 2011

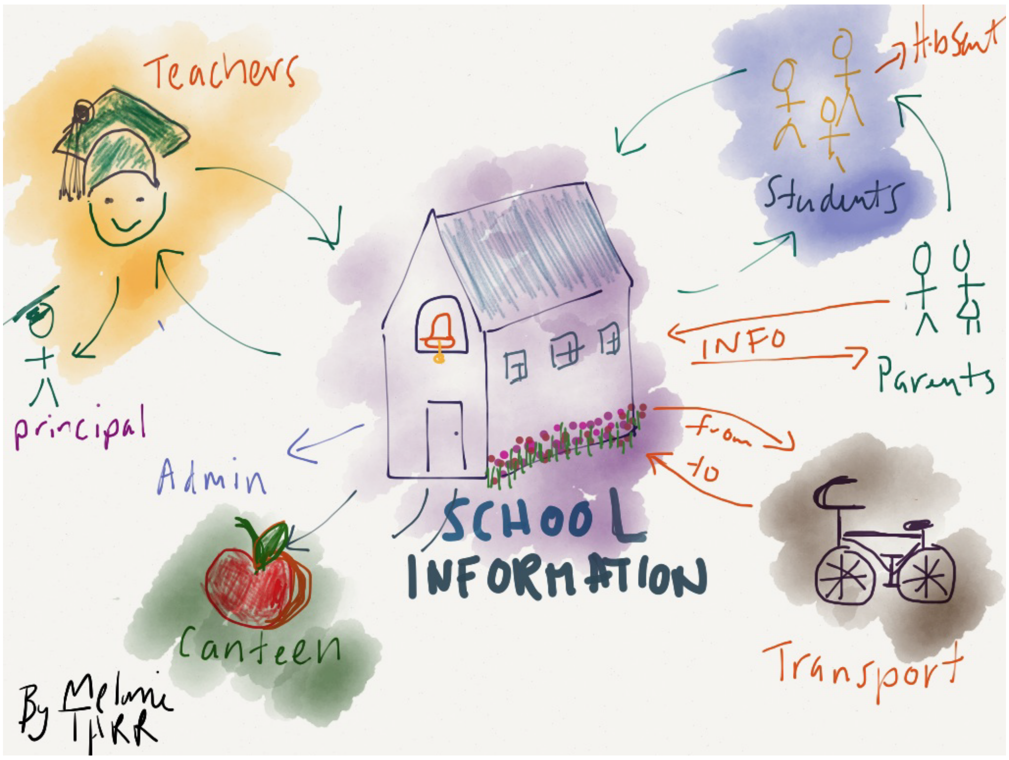

FIGURE 1.2: Rich picture of app ideas for school, 2012

After this realisation my two colleagues and I began to formulate an outreach program for adolescents that could deliver learning technology; however, no suitable visual format for adolescents existed that matched the care and detail of the programming language. I believed at this stage that the answers to mass communication for complexity lay in the field of graphic design and that its communication was beyond the cosmetic aspects.

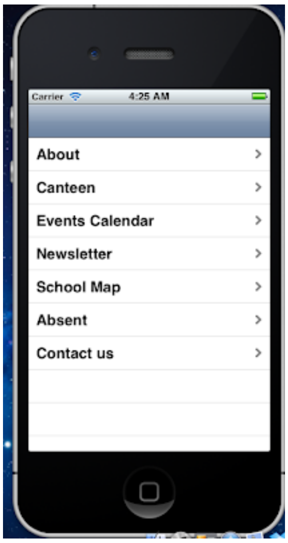

FIGURE 1.3: Main menu

After a successful grant application, a new outreach program began that produced the world's first iOS app by students in 2012 (Tarr, 2012). I know it was the first, because at the time, I performed an extensive search of Australian and international high schools to try and find a precedent. There was one school in Australia doing app development with the students and they had substantial financial resources, flew every student to an international conference and these students were not developing the app. I needed a model for low socio-economic schools that included the students performing the work. The initial idea was to produce something the entire school would use (see Figure 1.4).

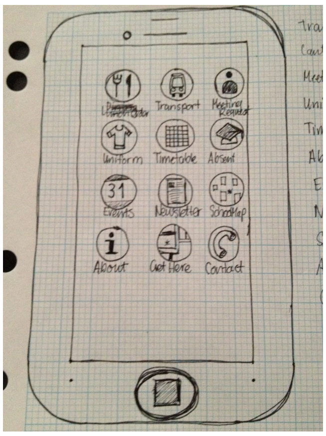

FIGURE 1.4: Sketch of main menu

I developed these ideas into sketches (see Figure 1.5), the app was developed to automate many of the school functions. This included a feature to report absentee students, lunch ordering via the canteen and a way to individually email each teacher (see Figure 1.3). The project was quickly self-funded because of because of demand from the high school decision makers on what outreach programs should be brought into the schools.

FIGURE 1.5: First static prototype of app screen for main menu, 2012

FIGURE 1.6: Screen shot of school map feature

While this outreach course was running, I witnessed many changes in technical knowledge and behaviour of the students during this time. In traditional computer programming teaching, programming is taught by getting students to copy code from a book or screen into a computer. Somehow, the visual communication within the curriculum I had created was communicating deeper learning to the students beyond the copying of code. As I come from a family of professional picture makers going back to the 1800s, this research into programming and pictures was a natural progression. My thesis is an enquiry into the communication of visual complexity. Some of literature examined within this work is older than 10 years. However, there is not a lot of research available on the gap my research addresses (see Chapter 4, Section 4.1.2) although many inroads have been made into teaching children programming within the last decade.

1.2 Programming in Year 8

It is widely accepted that computational thinking should be considered a mandatory part of adolescent learning (Tversky, 2015). My work considers adding a visual emphasis to a computing curriculum for Year 8 children. Through approaching computer science visually, I will attempt to communicate the abstract operations of computer programming. In addition to this, I intend to raise awareness of visual communication and learning computer science within the broader education community. Much instruction exists online for teaching coding to children. Most of it lies outside of the research scope of TOAOCP. I do not consider learning systems that use animation, video or photography for reasons that will be made clear throughout this thesis.

1.3 Learning programming through pictures

In this study I consider the role of the picture in adolescent learning. I also consider how design principles when used in conjunction with pictures assist the cognition of computational thinking. Within this thesis a picture "... is a record of what its creator has seen or imagined, made available for others to see or imagine" (Gibson, 2014, p. 291).

Pictures assist the creation of mental models in the brain and these mental models are organised through a schematic process. The brain creates knowledge and learns through spatial acquisition of ideas, that is, through schema. A schema is "... a cohesive repeatable action sequence possessing component actions that are tightly interconnected and governed by a core meaning" (Piaget, 1952, p. 240). The concept of a schema is reviewed later in the graphic design and learning sections (see Chapter 4, Section 4.2.3 and Section 4.3).

This project explores a set of reusable pictures as well as their application within lesson plans. They will be designed to assist the communication of programming. Design principles and theory such as visual realism (see Chapter 4, Section 4.2.2), synaesthesia (see Chapter 4, Section 4.3.3) as well as the Gestalt principles (see Chapter 4, Section 4.3.5) were used within this research work titled - *The Other Art of Computer Programming* (TOAOCP) to develop the instrumentation for the participants. There were a number of creative works produced as an outcome to this thesis that are referred to as the instrumentation and the milestones. Chapter 2, Section 2.2 describes the milestones that were developed after the instrumentation. The milestones and are the visual representation of computer history from the 1950s to the 2000s. Both artefacts (the instrumentation and milestones) utilise a number of graphic design techniques that are referred to throughout this thesis. The milestones are also static prototypes that can be enhanced with further interactivity. The instrumentation and milestones collectively form the creative artefacts for this research. The instrumentation was used in the quantitative data collection and is referred to as a prototype or comic throughout this thesis depending on the context. Both artefacts, that are, the instrumentation and the set of milestones are listed in Appendix A. Rather than focusing upon satisfying capabilities within the current Australian Secondary Education standards, the milestones were designed to contribute to the self efficacy of students.

The gestalt principles have been used to interpret form perception (Hattie, 2008) within TOAOCP and the principles of unity, proximity and grouping are used specifically in Chapter 4, Section 4.3.7. The law of proximity was applied specifically in the creation of Figure 4.13 in Chapter 4 by grouping the petals of a flower together. This approach is novel since design principles and thinking are not routinely used to teach programming.

Pictures are used in this research to explore computational thinking. This study attempts to visually highlight the skills and techniques used by programmers and developers in computational thinking and apply these in visual lessons for adolescents. These skills and techniques are listed in Table 1.1.

TABLE 1.1: Skills and techniques of computational thinking

Techniques	**Description**
Decomposition	Breaking a task into parts and steps
Pattern Recognition	Predicting and modelling to test
Pattern Generalization and Abstraction	Making laws and principles that cause these occurrences or patterns
Algorithm Design	Developing steps to solve similar problems so you can repeat this

The techniques listed in Table 1.1 are skills that can be applied to a variety of areas in daily life. For example, breaking a task into parts and steps can be represented as a visual process to a child by asking them to sort shapes or colours of Lego. A child can learn to apply computational thinking from a young age. As adults, an appreciation of these techniques and how to apply them is a skill set that is mandatory for computing positions. By acquiring a computational thinking skill set in Year 8, it is possible for a student to more easily develop technical knowledge such as writing mobile applications.

Computer science remains as a domain of mental imagery with no system or framework for non-linguistic representation that addresses what can- not be seen. Often when a piece of software is executed by an individual, the result is simply displayed with no indication of the steps occurring within the machine it operates on. The milestones (see Appendix A) illustrate programming in stepped processing order (see Appendix A). TOAOCP used pictures to explain what cannot be seen.

There has been much done in the visualisation for learning. A few artefacts have been created, particularly those that are app based, and there are online communities that are visually teaching children how to code. For example in the NSW education curriculum children are learning to code Scratch through drag and drop interfaces. Similarly, Minecraft is now another way that many children are learning the basics of coding. However, a drag and drop interface simply arranges a series of shapes upon a surface, this may produce a diagrammatic pattern but the interfaces rarely mirror a real world situation, and if they do (such as some of the app maker code.org designs), pictures have not been used in these interfaces. The commercial applications of Scratch in a real world scenario are limited. The jobs for employing app developers far outweigh the jobs that employ Scratch developers. My research is a case for learning programming beyond hours of Minecraft; it is through learning how to solve real world problems starting with picture based instructions. Infant coding was happening with products Alan Kay was using, such as Rubio's Box in the 1960s. The topic of very young children and coding is old. Mine is a fresh approach that prioritises pictures. While the code may need to change, the way the problem is solved in programming will not change. Programming has not changed substantially over the last 50 years. Pictures are a form of communication that does not often change, and you can see this in the icons that Susan Kare designed for the Macintosh in the 1980s. I also prioritise time-based events by use of the z-path and I do not focus on a spatial coding of building an imaginary house or use game based themes. I focus on real world application and how that can be communicated to students. For example - how do they build an uber app, instead of how do they navigate to an imaginary house in a digital world. The software I build has a real life/world application and a realistic grounded narrative.

1.4 The scope and state of digital literacy

In order to introduce the reader to the concepts used within TOAOCP, I will now give some examples of the pictures used to communicate some of the programming. The visual representations used to explain the programming to the participants look like the following prototypes. For example, Figure 1.7 to Figure 1.13 are pictures designed to communicate the concept of sorting within programming.

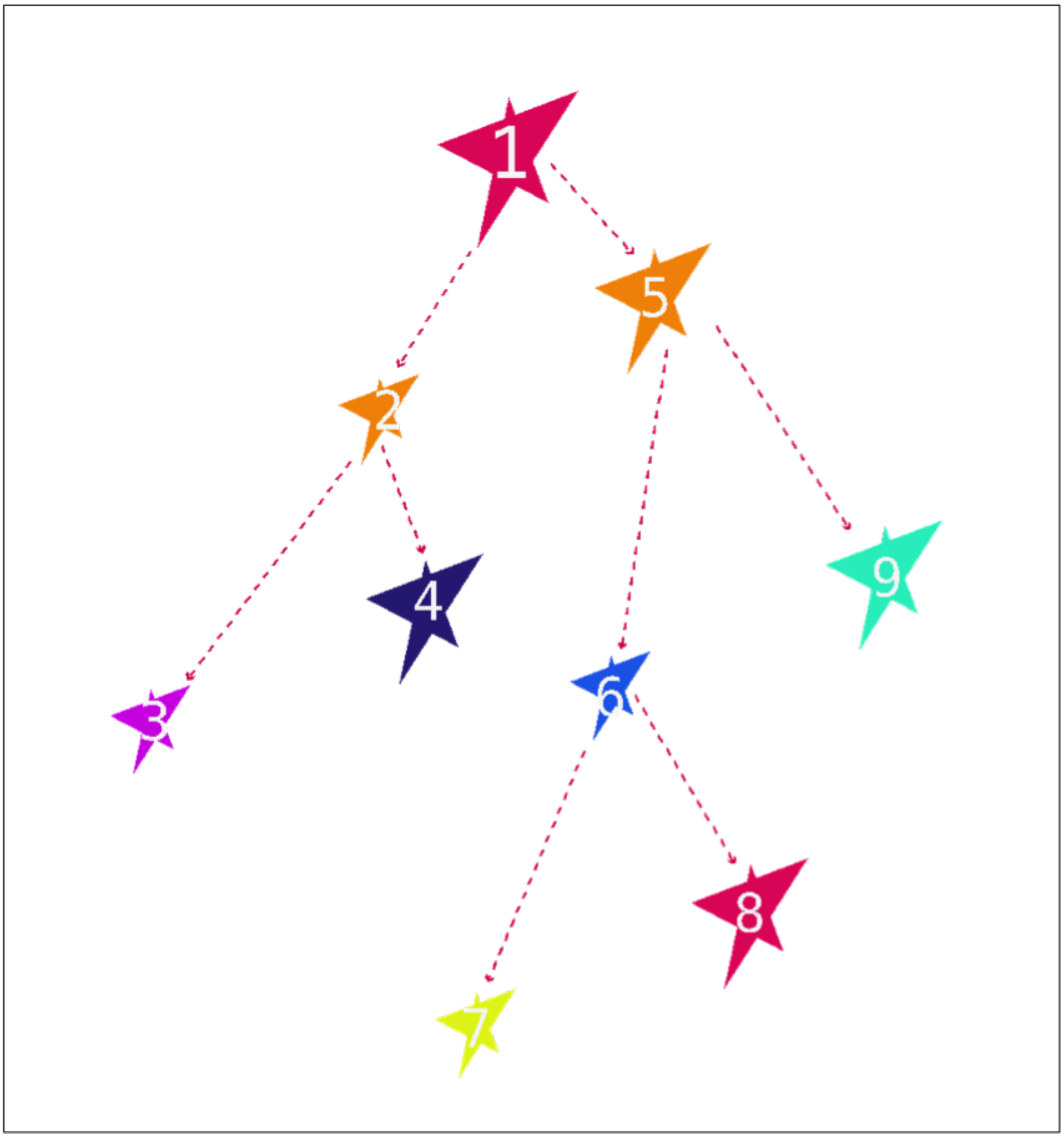

FIGURE 1.7: Binary tree picture used to explain tree traversal, Tarr 2015

FIGURE 1.8: Binary tree picture patterns, panel 1/7, Tarr 2015

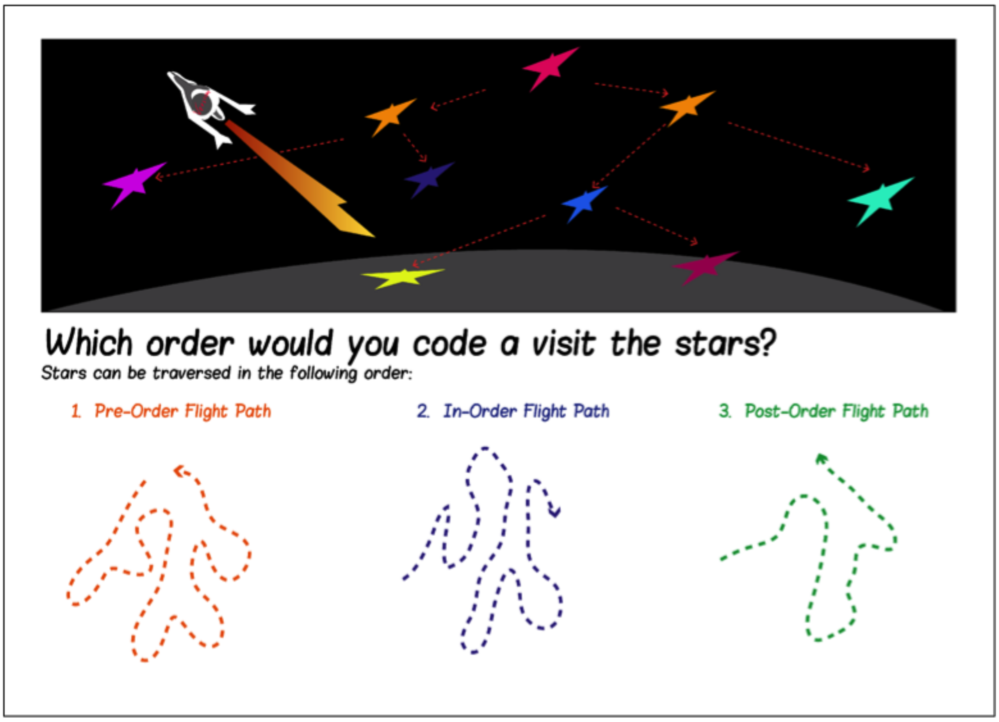

FIGURE 1.9: Binary tree picture patterns, panel 2/7, Tarr 2015

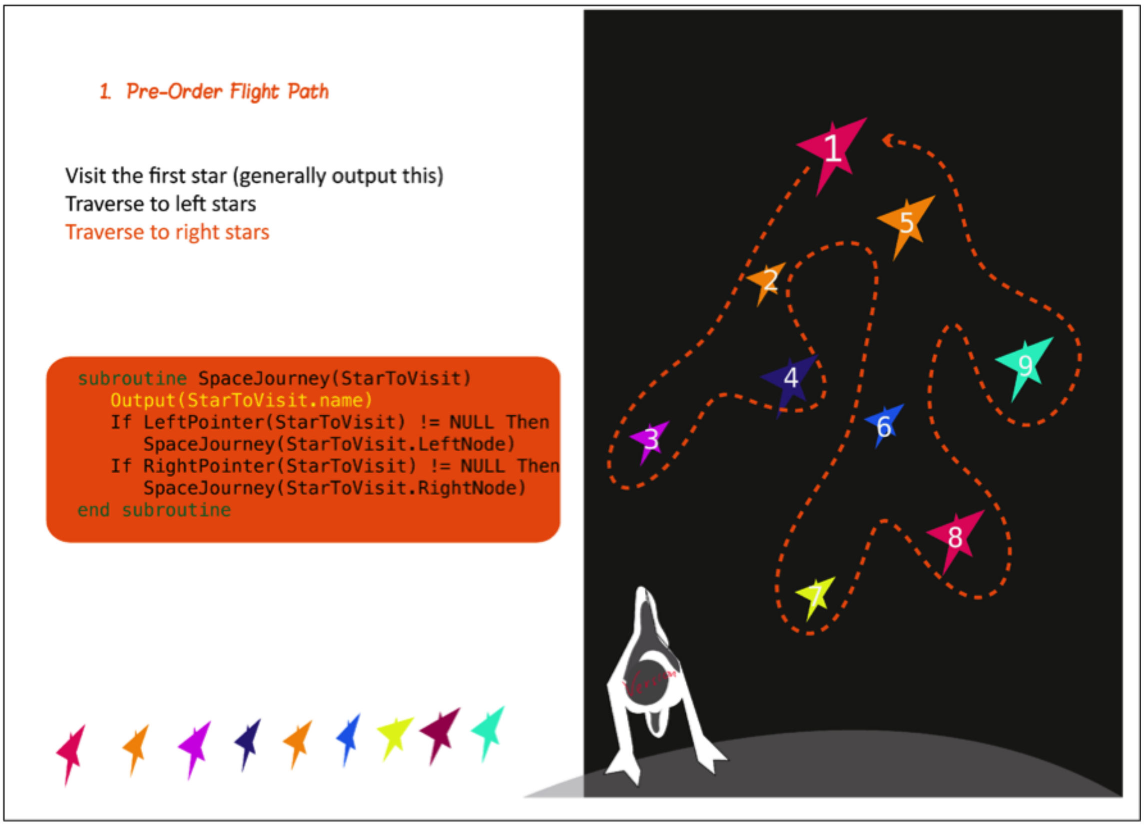

FIGURE 1.10: Binary tree picture patterns, panel 3/7, Tarr 2015

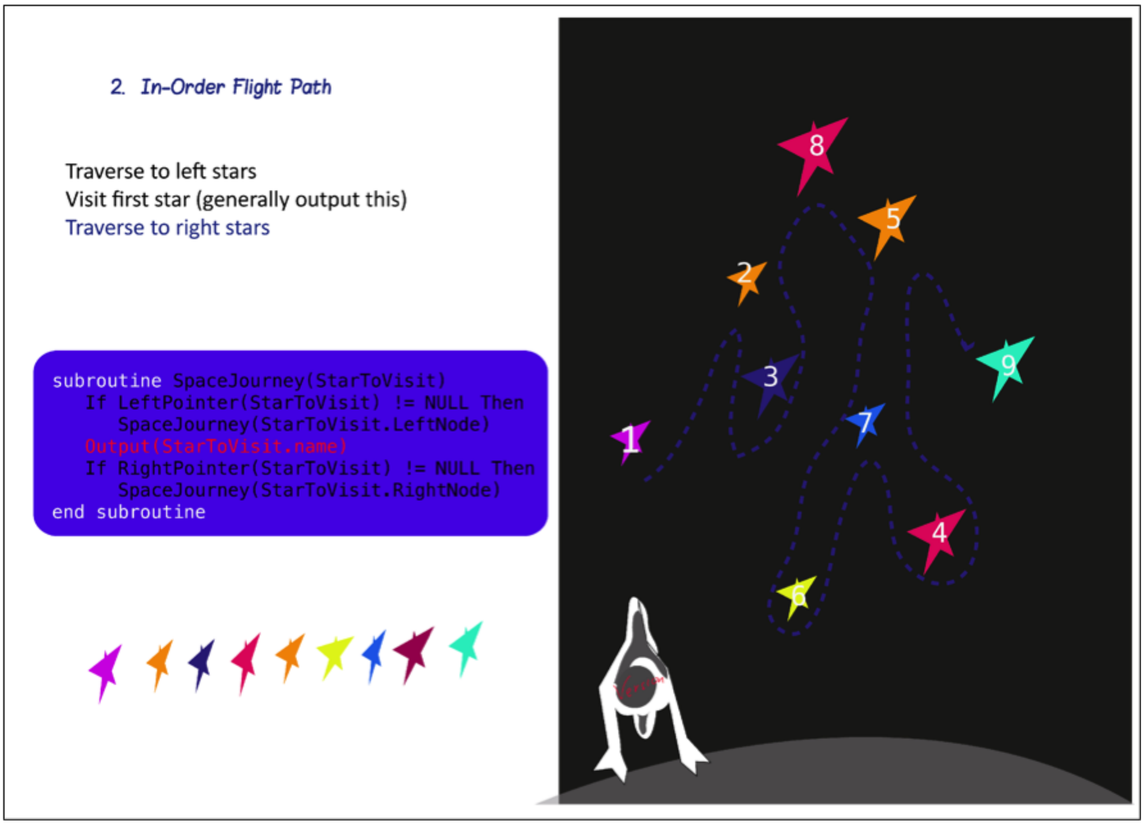

FIGURE 1.11: Binary tree picture patterns, panel 4/7, Tarr 2015

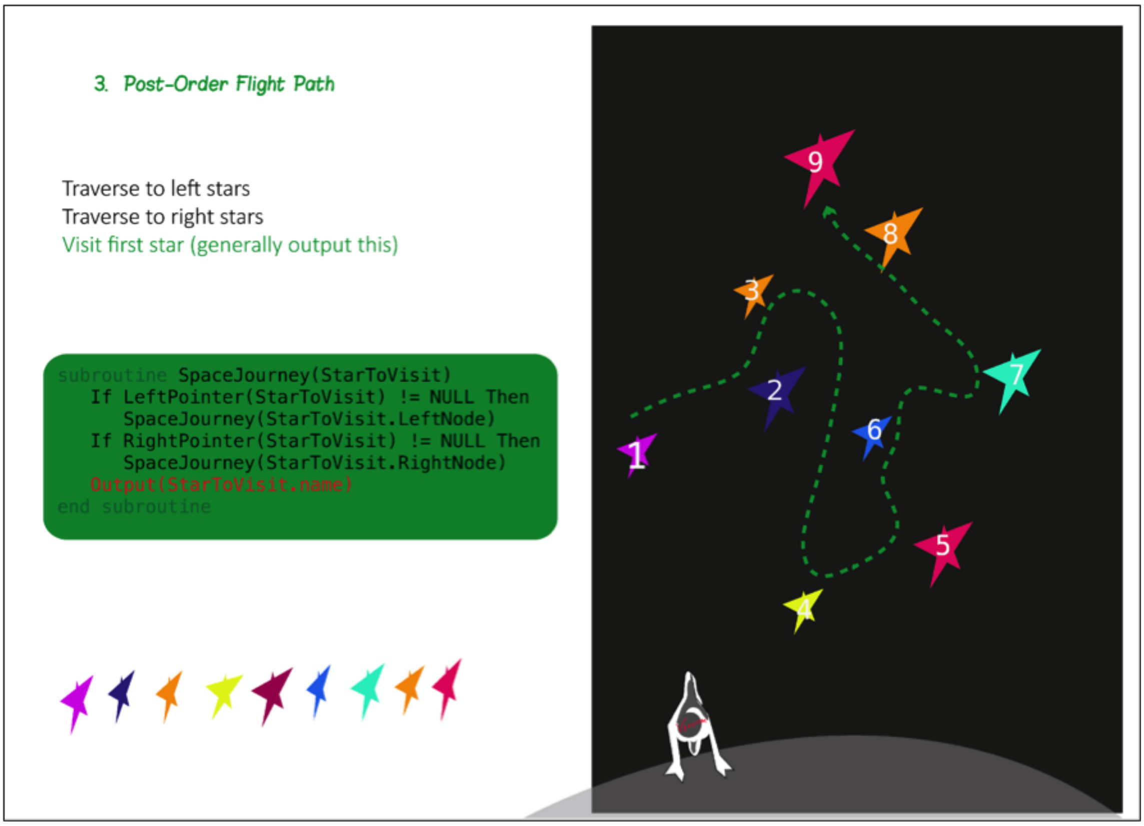

FIGURE 1.12: Binary tree picture patterns, panel 5/7, Tarr 2015

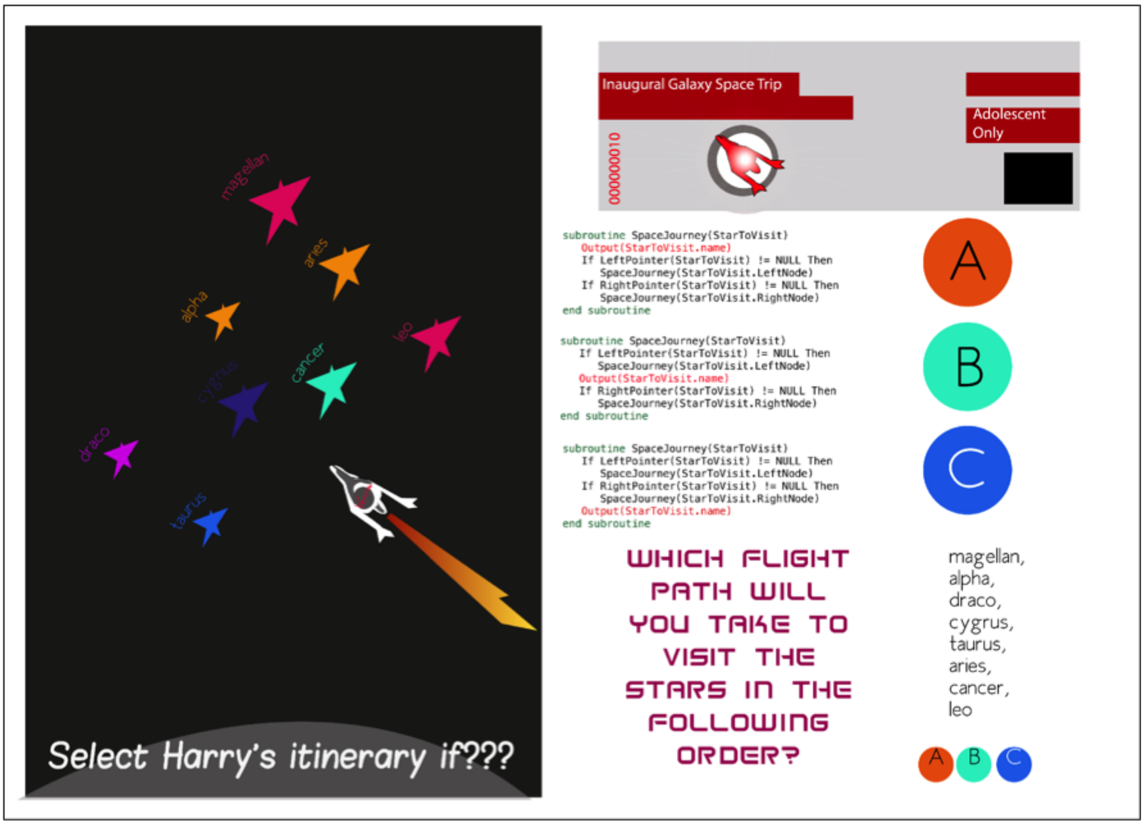

FIGURE 1.13: Binary tree picture patterns, panel 6/7, Tarr 2015

Digital literacy is based upon traditional literacy and is an individual's ability to find, evaluate, and create information through writing and other mediums on digital platforms (Jenkins, 2009). An individual is considered more economically secure when they are digitally literate. This skill set has become a core component of employability (Wynne & Cooper, 2007). Programming as a skill or even computational thinking is not yet considered part of digital literacy. School curriculums rapidly update and teachers must acquire knowledge of new technologies in short time spans. This acquisition of new knowledge within a short time frame can be a barrier to learning (see Chapter 4, Section 4.3.8). The literature review will reveal a lack of focus on where programming should be situated within the national curriculum. This study suggests that placing computational thinking and programming under digital literacy might be an appropriate place to start. Amongst the outcomes for the project will be a framework for learning computer programming through visual communication.

Digital literacy intrinsically does not address the role of pictures within learning. The research questions addressing this gap reflect a general enquiry into the impacts of visual communication, upon learning (see Section 3.1).

1.5 Participant involvement

The participant involvement was through survey and focus group discussions. Eight adolescent groups were surveyed in TOAOCP and the participants within the groups ranged in ages from 12 to 14 years. A full discussion of the participant sample is listed within the methodology (see Chapter 5, Section 5.4).

1.6 The structure of this research thesis

What follows is a discussion and overview of the PhD structure.

Chapter 2: Significance Brain research and traditional areas of learning used to communicate computer programming are addressed. Pictures are introduced as an area within visual communication that may hold some solutions to the issues involved in communicating programming.

Chapter 3: Purpose Three research questions are stated along with the general aim of the thesis, that is, the investigation of learning computer programming through visual communication.

Chapter 4: Literature Review The literature review is divided into three sections, namely, visual communication; computer programming and learning. Here a gap within the literature is identified. This gap is the role of pictures and learning computer programming. The reasons that pictures can be used as persuasive devices to affect learning and the adoption of successful methods to learn through are explored. The use of pictures in learning complexity is reviewed. The suitability of statistical models and adapting them to measure persuasion is covered in this chapter. Adoption of the artefacts by learners is discussed as an objective of the models. Particular focus is placed upon pictures as rhetorical devices. Measurement of and drawing the 'unseen' are also addressed within Chapter 4. The last part of Chapter 4 discusses the hypotheses as well as the manner that they were developed that is retrospectively.

Chapter 5: Research Methodology The research design discusses the order in which the research project was undertaken. The conceptual framework also resides in Chapter 5 and organises the theories within TOAOCP. The methodology discusses mixed methods analysis and its application to TOAOCP. The quantitative research is discussed first and the research plan and phases are detailed. A discussion on the variables and how they were adapted to study programming through visual communication then follows. The validity and reliability of the instrumentation was achieved within the pilot studies. The role of prototyping in design is then detailed and how the theory informed the construction of the instrumentation as a measurable process within TOAOCP. The focus group discussion process is also detailed along with the triangulation method. There is also reflection upon the quality and sampling used within the research.

Chapter 6: Results The statistical data are listed along with the focus discussion group summaries and outcomes.

Chapter 7: Findings and Discussion The research questions are revisited and answered in summary with the results from Chapter 6. As Chapter 7 was found to be in favour of all except for one of the hypotheses, this chapter explains the theoretical reasons why the resulting relationships concerning pictures, comics and programming may have occurred.

Chapter 8: Limitations, Future Directions Limitations of the study are also reviewed in this chapter and include the amount of class time devoted to TOAOCP as well as the total participant number. The implications of the results from Chapter 6 are contextualised in terms of the design process, and directions for further research are recommended. Chapter 8 focuses on key trends that position the discipline of design as knowledge-based. Knowledge-based economies characterise contemporary society and this knowledge is largely an unseen world of information. The design approach used to explore solutions for understanding this invisible information is different to the design approach used to solve problems in industrialisation where the issues were more readily seen.

Chapter 9: Conclusion The conclusion summarises what occurred during TOAOCP as well as justifying claims to the knowledge contribution. The pictures, the sequence and structures used within the designs of the instrumentation are readdressed, then the research questions are individually addressed and answered within the Methodology Summary.

1.7 Summary

The research questions are framed around a central theme that addresses why learners may wish to consider pictures for the communication of computer programming. Chapter 2 explores visual perception and brain research theory to further position the need in the significance section (see Chapter 2, Section 2.4).

The thesis investigates the persuasive impacts of pictures upon learning the complex discipline of computer programming. The theory of planned behaviour as an acceptance model is used to predict the participants' intent to use pictures to learn programming.

Chapter 2

Significance

The research proposes to contribute to three major areas. These are the disciplines of visual communication, computer science and learning. There are also minor contributions toward the field of psychology and learning theory. The impact on each of the major areas will now be examined.

2.1 Text based teaching materials in computer programming

The research attempts to produce a curriculum that uses pictures to explain these abstract formal operations. I explored the difference between traditional typocentric (text-based) and pictocentric (picture-based) learning materials. Structures such as algorithms and data structures exist within computer science to solve abstract operations. The literature review establishes the absence of pictures within the teaching curriculum of computer science. Because the outcome will approach computer science visually, it may have implications for those students who have not considered studying this discipline before. The way the curriculum presents may have an impact on a child's willingness to learn computer science. In this way, the curriculum model may have significance for the early high school student.

2.2 Programming milestones as an outcome of this thesis

The programming milestones were integral to the creation of this thesis because this participatory approach drew on the actual teaching practice of information technology educators in order to evolve the curriculum that forms the creative component. The 200+ page curriculum in Appendix A contains six lessons on modern computer programming that are referred to throughout TOAOCP as the milestones. These lessons include computational thinking concepts. Each 20-60 page lesson will illustrate an important milestone within each decade from the 1950s onwards. The first lesson will be an exception, as it will contain some visual illustration on mechanisation and automata that predates 1950. These illustrations are necessary to visually contextualise the innovative progression from mechanical to electromechanical through to digital processes. I hope the curriculum fills a gap by illustrating the history of the discipline that has been acknowledged as not easily communicated through education (*Interview: The 'Art' of Being Donald Knuth*, 2008).

2.3 The demand for programming skills within the Australian economy

This research takes place at a time when demand for programmers exceeds availability of programmers in the work force. Research has found that while the education of programmers stays in a traditional format, attrition rates within universities remain high within programming courses, and the shortage of programmers within the workforce fails to diminish within Australia (Morgan, 2017; Nott, 2017; Stein, 2017; Morgan, 2017; Sachdeva, 2018). However Australia is not alone in this shortage (Hager, 2016), according to Facebook and Microsoft by 2020 there will be one million programming jobs left unfulfilled (Ravisankar, 2016b, 2016a). In addition to the programmer shortage, some countries have no computer science courses within K-12 education (Lockwood & Mooney, 2017). The shortfall of programmers has not gone unnoticed by Australian policy makers, as reflected in the following statement from the recently retired Prime Minister, Malcolm Turnbull:

> App development is becoming one of Australia's strengths and one where we can compete with the best in the world. Dr Mandel's report finds that there are 139,000 jobs in the Australian app economy. In Sydney, 10.7% of ICT jobs relate directly to app development, more than in New York, Chicago or London - albeit a long way from Silicon Valley's 17.6%. (Turnbull, 2014, 9)

Further political commentary highlights the importance of this issue with the Honourable Minister for Industry, Innovation and Science, Arthur Sinodinos stating:

> While computer coding occupies a far greater role in the proposed National Curriculum than in any Australian syllabus previously, the current proposal is for a dedicated technology subject only from Year Nine. (Sinodinos, 2014)

Three years later the problem of how programming was to be organised, administered and what discipline it was to be positioned under within Australian schools was still receiving negative attention as stated in the following report by the Australian Broadcasting Coorporation (ABC):

> At present, there are no standardised coding classes in Australian schools. Instead, parents are stumping up hundreds of dollars for extra-curricular coding classes for their kids. (Docherty, n.d.)

Within the same article from the ABC, Dr Therese Keane the deputy chair of education at Swinburne University stated the following:

> Coding has become heavily commercialised and there is almost a fear that if your child isn't doing [it], the child is missing out ... I have to then ask — why aren't the schools doing this within the curriculum? (Docherty, n.d.)

The seriousness of not understanding code appears to be reflected worldwide. For example, the British government's reaction was to make programming mandatory in its schools (McNeilage, 2014). The commercial sector is also aware of the need for the demand in the education of our future programmers. Companies that employ programmers such as Google Australia remark on the difficulty of matching the computing skills they need with what high schools offer to students. They state that programming is vital and caution Australia against going backwards (Critchley, 2014). Accompanying this is a decline in the enrolment rates within computer science nationally and internationally (Rossi, 2013). Curiously, programming was positioned under the subject of Design and Technology in the 2015 draft of the Australian National Curriculum (*Design and Technologies Curriculum*, n.d.). Glenda Johnstone, President of the NSW Information Communication and Technology Educators stated at the time: It is unclear whether computer science would be a separate course or incorporated into existing subjects... It's just a waiting game to find out what happens and what decisions they make (McNeilage, 2014). Despite this ambiguity, support still existed for the incorporation of computer science into high school subjects. High school commentator and computer academic Mathew Rossi stated that by:

> ... developing a rigorous senior high school Computer Science curriculum, it is entirely possible to address the shortfall in computer science students we are currently facing. (Rossi, 2013, para: 23)

Significantly, this research has identified a theme of inclusivity that has been addressed in the programming milestones. Ideally this aimed to increased the number of children that understand programming in a classroom situation, thereby accommodating the high demand for more programmers to address this shortfall. As will be reviewed in Chapter 4, Section 4.4.3, all disciplines need to appreciate and have an awareness of computational thinking and computer programming because technology is integral to modern existence. Early introduction to programming concepts through pictures could ease the transition into coding towards advanced development, as pictures have an impact upon cognitive load and information anxiety (see Chapter 4, Section 4.3.8).

2.4 Neurology and cognition, how learning occurs and factors that influence the learning process

Research into neurology and cognition is an emerging global trend. My project contributes to this trending research area by looking at the positive affects experienced by a learner when using a visual curriculum. The American President's fiscal year budget in 2014 allocated $100 million as well as additional support from national research bodies into The Brain Initiative. Formally defined, The Brain Initiative is giving scientists the tools they need to get a dynamic picture of the brain in action and better understand how we think, learn and remember (Obama, 2013).

It is clear that information on how humans learn is subject of current worldwide academic debate (Cory, 2013). My research aligns itself with current research on neuroscience and Piagetian theory. In the literature review, pictures are found to contribute to learning science, however, not specifically within computer science. The review also found that a visual communication approach to curriculum design within computer science is yet to be developed. The brain is capable of understanding abstract concepts and the impacts upon this understanding come from a variety of factors. Cognition and motivation both impact upon the way an individual learns. As well as these impacts, my research focuses on affective factors that are not as measurable.

Affective factors are not as easy to quantify. 'Affect', for the purposes of this study, is a term that encompasses mood, emotions, and feelings (Zhang & Li, 2005). The reasons why pictures are often viewed as an aesthetic add on to learning are examined through the role of pictures within learning. Although affective factors have been known to impact learning for some time (Zeki, 1999), research into the impacts of visual communication upon behavioural affects is less common. Affective factors form a holistic part of the design process that has a beneficial affect upon meaning-making or learning. This project specifically utilises graphic design, that is, the representation of information and concepts that combine both pictures and text. Other graphic design concepts such as visual hierarchy and gestalt were utilised within the instrumentation of TOAOCP. Affective factors are examined before and after learning through these graphic design concepts. I also collected data from the participants measuring the success of the graphic design concepts. Graphic design is considered "... to give order to information, form to ideas, expression and feeling to artefacts that document human experience" (Meggs, 1983, p. 5).

As well as the above issues in computer science, the recent emergence of Art Science Labs in the United Kingdom firmly positions design as helping to solve problems that cannot be solved in engineering labs (Edwards, 2012). This emergence represents an approach where design is an essential tool within the problem-solving process. It is interesting to note that design is assisting in these complex technical problems and in many cases can produce solutions. As TOAOCP is a design based curriculum intervention, it is also unique as behavioural intervention studies are rare (Gardner, 2015; JaKa et al.,

2016) and even less so within design research. Most studies that seek to influence behaviour through beliefs and values come from " ... social and environmental psychology and allied fields" (Lockton, 2013, p. 31).

The three predominant areas of significance addressed here are visual communication, the learning process and computer science. The role of the picture and visual communication within the learning of computer science is not nearly as dominant as the use of mental imagery by learners as will be revealed in the literature review. Neurology and cognition is a global trend, however, how these impact upon learning through design methods is yet to be explored. Lastly, there is a shortfall of computer programming skills both nationally and internationally. The outcomes from this research will attempt to contribute to these three areas as well as answer the research questions which will be detailed in the next section.

Chapter 3

Purpose

This hybrid mixed methods study will address the lack of visual communication within the learning process for computer programming. The quantitative analysis will provide data on the cognition, motivation, beliefs and values to learn computer science through visual communication while the qualitative data will triangulate and add richer meaning to the measured information on the discipline of programming. The main aim or purpose behind TOAOCP is to examine the impacts of visual communication on the learning of programming. This aim is focused through the research questions.

3.1 Research questions

The following research questions are used to determine the efficacy of using visual communication in a computer programming education context:

1. What are the impacts on cognition of using pictures in learning computer programming?
2. What are the impacts on motivation of using pictures to learn computer programming?
3. How are a Year 8 student's values and beliefs about computer programming impacted through using a visually designed lesson?

To examine these questions, four broad areas form the literature review: visual communication, the learning process, computer science and lastly the theories on adoption of technologies. These areas aim to explore the junction between visual communication, abstract concepts and graphic design. This junction between these areas will enhance the factors of the learning process listed in the methodology. Cognition, motivation and perception are also examined. By examining many different impacts of using pictures to learn programming through, I answer the research questions through quantitative analysis and then focus group discussions. The impacts have been researched according to the theory of planned behaviour (Ajzen, 1985). These impacts determine why a learner would choose to use a particular technology to learn with.

Researchers have long espoused the connection between visual imagery and effectiveness of instruction (Alesandrini, 1981, 1984; Alesandrini & Rigney, 1981a, 1981b; Rieber, 1994; Dwyer, 1978) along with learning and memory (Rhodes & Castel, 2008; Diemand-Yauman et al., 2011). Design features such as visual realism as well as some gestalt principles were utilised within the pictures and layouts created for TOAOCP. These features have all been utilised for learning purposes and to examine a role for graphic design in education. Pictures used in learning can be designed to have features that help create mental imagery within the learner. Within TOAOCP, techniques and theories used by graphic designers such as creating line art, the Gestalt, and comic book theory have been utilised in the milestones to help students learn computer programming. According to Goldsmith (1984); Leneway (2018); Gurri, Denny, and Harms (2010) and (Gillenwater, 2009); visual literacy is a skill that can be taught to learners and within TOAOCP the purpose is to build pictures that also take advantage of the way that we see.

The purpose of using pictures and layouts in TOAOCP that take advantage of the innate way in which we see is to build mental images faster than the way in which a linguistic text would build them. In addition to this, mental imagery, according to the definition from Kosslyn (1994) and before that Pylyshyn (1973) is what programmers use when they are writing software. Petre and Blackwell (1999) state these mental images are visual. Mental representations (Lakoff and Johnson 1980, Kosslyn, 2006) enable problem-solving (Mani and Johnson-Laird, 1982). Petre and Blackwell (1999) further state it is the quest to find these representations in the mind that should guide the development support tools for programming and software design.

Research into mental imagery is used for the design of digital displays and cognitive science for the visualisation and interaction of big data (Hegarty, 2011). External representations assist cognition when they are accommodated (Zhang and Norman, 1994). Visual metaphors are a form of external representation that encourages mental imagery within learning. Pictures are the visual metaphor used within TOAOCP.

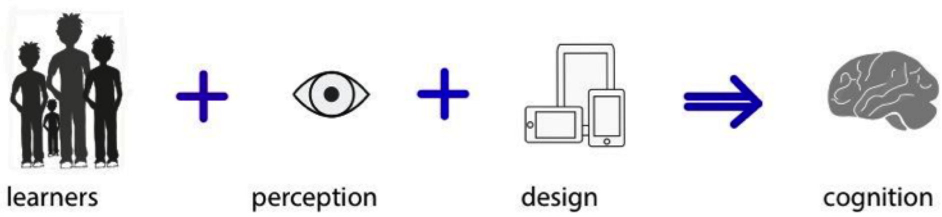

FIGURE 3.1: Graphic equation of the research aim within TOAOCP

The above Figure 3.1 illustrates the factors that my thesis examines. Graphic formulas like the one above give a path into understanding related concepts through their use of pictures over letters. The artefacts produced in TOAOCP changed as new aspects or factors that affect the learning process emerged through the research. The literature review which follows examines the role of pictures within graphic design; looks at the roles of pictures in learning; examines the existing role of diagrams and pictures in computer programming and lastly discusses the theories behind the measurement of the impacts.

Chapter 4

Literature Review

4.1 Introduction

4.1.1 The structure of the literature review

The literature review is structured around, firstly the gap in the literature followed by four themes that form the conceptual framework (see Section 5.2). I have researched these themes firstly to establish the hypotheses and secondly to form a theoretical explanation of the results. The four themes within the literature review are:

- A pictocentric approach - learning programming through pictures (Section 4.2);
- Psychology and interpretative faculties of vision that contribute to learning computer programming (Section 4.3);
- Ways of learning computer programming classed as "visual" from text to digital (Section 4.4);
- Measurement and theories of why people adopt a learning technology (Section 4.5).

There are two reasons to examine the visual communication side of computer science and the pictures used to teach it. The first is to examine pathways for solutions to the research questions (see Section 3.1) for the target audience of this study, namely Year 8 students, and encourage them to consider computational thinking in an alternative visual form. The second is to provide evidence that illustrated documentation enhances the understanding of computer science.

This literature review, explicitly considers the dominance throughout the history of computer science of textual instruction materials. A set of instructional materials for computer programming accompanies the writing of this thesis and these milestones were explained in the previous paragraph. These materials, as an integral part of TOAOCP, tested ideas that emerged from my creative process in the creation of the milestones (see Appendix A).

Figure 5.3 is a diagram of the conceptual framework developed for TOAOCP that is discussed fully in Chapter 5, Section 5.2.

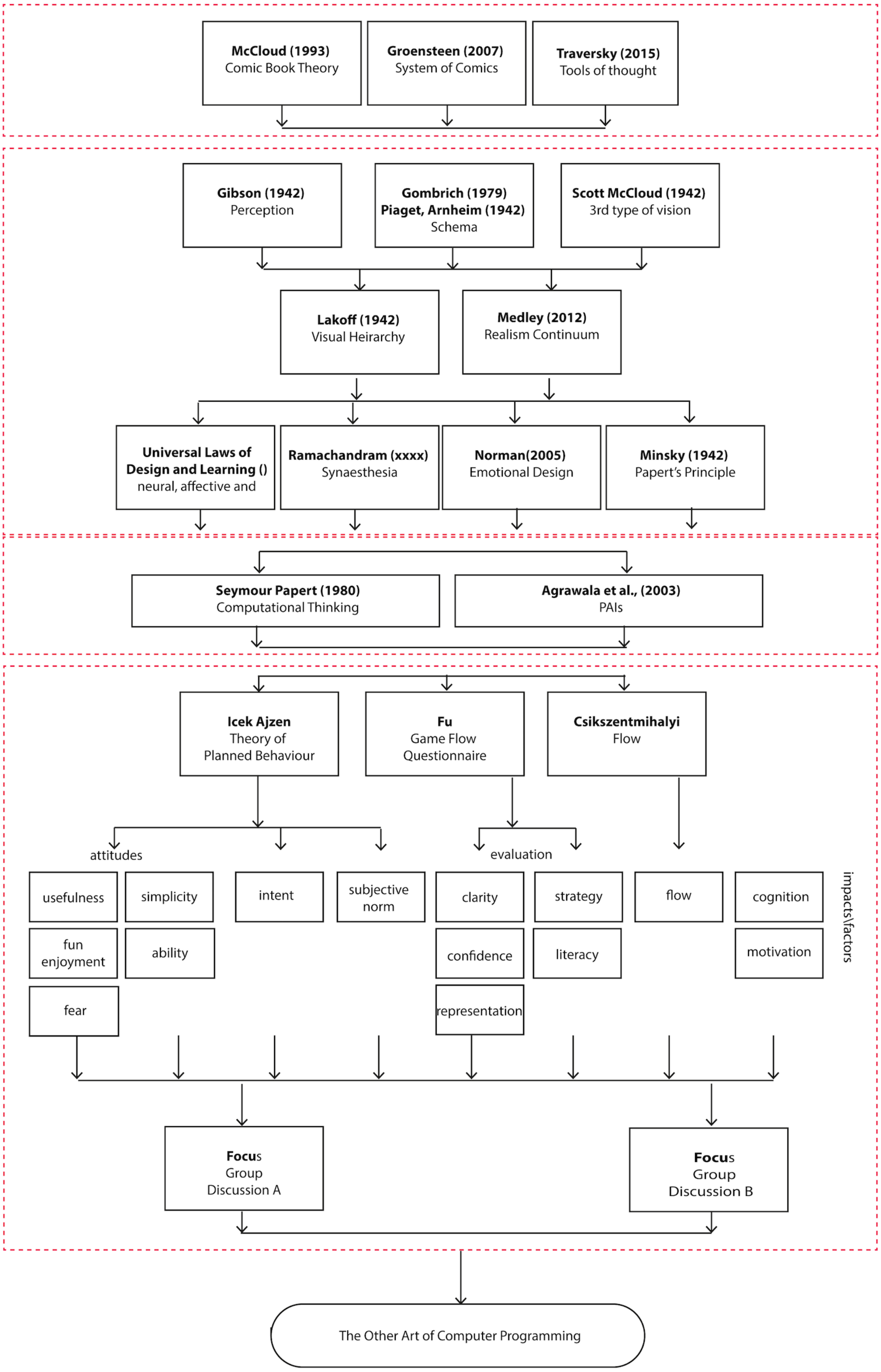

FIGURE 4.1: Conceptual framework for TOAOCP

Philosophy, semiotics and this research

A full semiotic analysis of the image was outside the scope of TOAOCP. However this research took into account Kantian Theory which documents the role of the picture in the depiction of knowledge acquisition (Arnheim, 1969; Deleuze & Guattari, 2014). Also Peircian logic was considered within this thesis (Peirce, 1974). To examine the role of the picture, in learning for adolescents, it is necessary first to define 'what a picture is' according to direct perception or how we see. If a person possesses the ability to see, sight is the dominant biological sense used to communicate. James J. Gibson was a psychologist at Princeton University in the 1930s and a visual perception expert on pictures. According to Gibson, information in ambient light received by the eye does not only contain colours and forms, but invariants. He states:

> ... a picture is a surface so treated that it makes available an optic array of formless invariants at a point of observation. (Gibson, 1975, p. 228)

The above descriptions of a picture, refer to what it represents, regardless of any cognitive process that occurs after the eye receives the image of the picture. After seeing a picture, the viewer takes the appropriate action as required. This study prioritises the role of pictures in learning and considers a perceptual response, or what the picture represents as an interpretation of a schema, as well as its relationship to image and rhetoric. Schema will be discussed in depth further within the learning section (see Section 4.3.2). The types of pictures used within communication vary depending on their purpose. Accordingly, the milestones (see Chapter 2, Section 2.2) have been created using line art or less than realistic pictures for TOAOCP (see Appendix A). Picture classification can occur through a continuum. The level of visual realism adopted by an artist is a factor that alters the meaning of the picture presented and is discussed later in the literature review (see Section 4.2.2).

While some disciplines have ways of classifying a picture and its role within learning, design theory has dodged the reasons behind the construction of the image and its associated perceptual laws. This thesis therefore applies pictures to the learning of computer programming and is an example framework. Pictures generally improve learning complex information (Bobek & Tversky, 2016), and I use them within visual design to teach computer programming.

The aspects of perception, cognition and realism place visual learning within the contemporary environment of the Year 8 adolescent. The literature review starts with a discussion on visual communication theory and draws attention to current research that acknowledges that graphic design principles are often not used to create the materials for programming.

Visual communication theory

Sless (1981) states that "Visual communication is the conveyance of ideas and information in forms that can be seen. Visual communication in part or whole relies on eyesight" (p. 187). This definition places visual communication firmly within the domain of the senses by raising the physiology of eyesight and by stating that eyesight is only part of the communication process he leaves room to extend the definition into how the brain further interprets a message.

Frascara (2004) stated that a good design of visual communication is measurable through audience comprehension. He further notes "... visual communication design is not just about looks; it is fundamentally about performance" (Frascara, 2004, p.12). The emphasis is on the interpretation or how the visual argument works after the visual communication artefact is sighted. The participant's reaction to the impacts, as well as comprehension, was used to measure the affects of pictures within TOAOCP (see Section 4.5). Visual communication experts tend to focus more on the organisation of pictures and images rather than the creation of them. This is a function of many visual communication theorists applying semiotics to their understanding of pictures. Semiotics is useful only for picture analysis (the pictures must pre-exist), not for picture construction.

Graphic design (see Section 4.2.3) was used within TOAOCP to produce the visual communication artefacts (see Appendix A). Although graphic design is a form of visual communication (Hollis, 1994), this communication is only successful when meaningful and the message can be interpreted by the viewer. Visual communication theory along with graphic design, visual realism, the gestalt principles, information design, synaesthesia and caricature are not routinely applied to computer programming teaching. It is this gap that TOAOCP seeks to explore and test throughout this research.

4.1.2 Gap this literature review addresses

Computer science academics have long stated the need for a formal inquiry throughout the teaching of the discipline along with clarity on how to do this (Lethbridge et al., 2007; Bollin et al., 2016; Bollin & Sabitzer, 2015; Gutierrez et al., 2018). Computer science is concerned with theories founded on patterns of information and how to abstract and compute that information. Computational thinking is the predecessor to these ideas. Several researchers note the need for design, consolidation of curriculum communication, and better guidelines on how to teach computer programming (Bell-Allen, 2016; Ben-Ari et al., 2004; Pears et al., 2007). Ben-Ari and Pears have voiced blanket criticisms that concern the teaching of computer programming. There is a sharp criticism of the number of screenshots (see Figure 4.2) that exist within the documentation and the limitation of these (Horton, 1993; Blevis et al., n.d.). The screenshots are of the human-computer interaction (HCI) or graphical user interface (GUI) displaying the coding language. Programming is not necessarily represented through the GUI at a deep or meaningful semantic level as it could be through the use of diagrams or pictures.

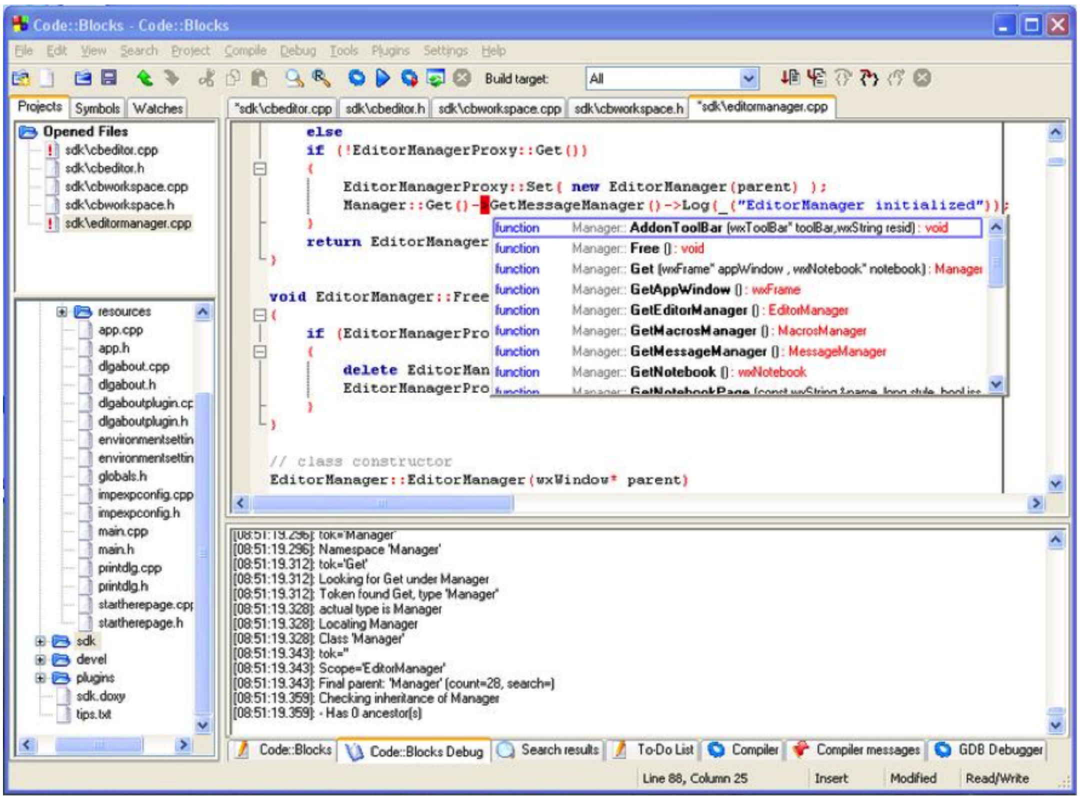

FIGURE 4.2: Codeblocks screenshot, GNU Free Documentation License

Although screenshots do support learning computer programming, it is hard to determine precisely how much assistance they actually provide (Gellevij et al., 1999, 2000). Despite this fact, screenshots are images and therefore on some level do support the learning process of computing (Gellevij, 2002; Gellevij & van der Meij, 2004; Carroll & Rosson, 2006; Van der Meij, Karreman, & Steedhouder, 2009).

Visualisations as computer programming communication

There are teaching methods within computer programming that make use of pictures. The most used digital methods are software visualisation, which is an established discipline within computer science, and textbooks used to teach novices. The type of software visualisation that I have experimented with in TOAOCP is source code visualisation, that is, using hand drawn pictures to explain the line by line execution of a software program. Software visualisation is defined as software visual information that is part of a software system. The visualised part is either the structure of the program (Staples Bieman, 1999), characteristics of execution (Trumper et al., 2013) and behaviour (Kuhn et al., 2006, Stasko et al., 1997) when the program runs (runtime behaviour) Diehl, 2002; Diehl, 2007; Knight, 2002). These visualisations are static, animated, 2-D or 3-D in form (Marcus et al., 2003; Wettel et al., 2007). Software visualisations can also represent the evolution of a software system.

Through different media, print and digital, authors have the opportunity to make use of pictures in their respective types of communication. The problem is not that computer scientists cannot see what their code is doing. Instead, it is more related to the effectiveness of the communication of software concepts through the documentation to the reader. In support of the preceding point Chiu (2015) states:

> It is found that the examples lack abundant guidance of problem-solving steps for students, especially little attention was paid to problem analysis, solution planning and testing/debugging step. Most examples focus on the description of program codes rather than the detail steps of problem-solving. (Chiu, 2015, p. 223)

The visualisation issues in programming concerning lack of clear communication are also somewhat mirrored by an academic view of programming communication on the whole echoed by Knuth and Denning in Section 4.4.3. This section (Section 4.1.2) now addresses the effectiveness and clarity of programming textbooks that are another media that utilise picture and image communication to convey complexity.

Textbooks as computer programming communication

The reason for examining the topic of textbooks in the education of programming is because a school of thought exists that manuals and documentation are unnecessary. When the introduction of the graphical user interface (GUI) occurred, key industry players questioned the use of any instructions including programming tuition beyond those displayed on the screen. For example Steve Jobs believed the success of the Macintosh computer was because it had a GUI that imbued "... meaning beyond the simple linguistics" (Novak, Feb 1985) he further stated, "People will not read those damn 400-page WordStar manuals. They won't carry around these cards in their pockets with 150 slash-W-Zs. They're not going to do it" (McCracken, 2014). A specific example of an excessive manual like the one Jobs would have been referring to is WordStar Reference Manual 3.3 released around 1983 (McCracken, 1983). However despite the early expectation that the GUI would be naturally intuitive, textbooks have remained the main teaching tools for computer science education. An extra set of communication is required in addition to the GUI in order to navigate these software systems meaning a user has to decipher first a text, then understand a GUI and before even getting to the complexity of the coding. The significance of this argument is that there seem to be multiple linguistic systems integrated into each other in order to communicate programming. Programming text books are the standard method of information delivery in high school from teacher to student. There exists a substantial communication problem with these resources. Despite the frustration with the current state of programming communication for novices, the topics addressed in TAOCOP such as presence of less realistic pictures, information design or the gestalt principles are not used to assess these traditionally accepted ways of educating programmers.

School textbooks are "... a tool which closely follows a curriculum and is adapted to the student's cognitive abilities and prior knowledge ..." and "... is a vital element in the daily work in schools from both the students' and teachers' perspectives and is a source of facts which are presented clearly for students" (Hajdin & Divjak, 2016, p. 21). Goran Hajdin and Blazenka Divjak analysed sixty-two papers on topics related to textbooks on programming communication and concluded that textbooks are the most "... commonly used tools" (Numanoglu & Bayir, 2009, p. 22). These textbooks were the most important sources of valid information in the process of education. They noted the sparse amount of research into the field of informatics and the "... challenge for the authors, particularly in view of the fast pace of change in the field" (2009, p. 22). As there was no Australian precedent at this time concerning the effectiveness of computer science high school texts, I searched internationally for a precedent in this area. Turkish researchers Numanoglu and Bayir's (2009) research paper was not interested in the format or media of the text but rather in the pedagogical practices presented within. After extensive citation network analysis, Hajdin identified a boost in student motivation that he attributes to the organisation of one of the textbooks in the lower secondary schools. Although graphic design techniques were not examined within Hajdin's study, it is important as it found the learning materials impacted the motivation levels of the students. Motivation was an impact examined in TOAOCP and is discussed later within Chapter 4 (see Section 4.5.4).

The programming text was unique in that the authors used "different teaching methods and tools including mind maps, illustrative examples..." (Numanoglu & Bayir, 2009, p. 31). Hajdin further cites other programming experts that have found that textbooks should be modular in instruction and that content, software and authorship (see Section 4.2.3) need further research (Dicheva et al., n.d.; Freiermuth et al., 2008). Numanoglu and Bayir looked at the programming textbooks according to visual design and concluded that the textbooks are the most popular tools (Numanoglu & Bayir, 2009). This visual design, did not consider pictures (see Section 4.2), comic book theory (see Section 4.2.1), information design (see Section 4.2.4), gestalt theory (see Section 4.3.5) or other diagrammatic tools (see Section 4.2.4) that are discussed within this literature review.

The research on textbook use within secondary classroom settings revealed that students only used texts when explicitly instructed to do so and that there should be a variety of resources available (Driscoll et al., 1994). Gottfried (1990) indicated that sometimes teachers are unsure of what best practice actually means regarding textbooks. Hutchinson and Torres (1994) highlighted that textbooks have a clear role as agents for change. Shymansky et al. (1991) acknowledged that the quantity of information a student is expected to absorb contributes to cognitive load however teachers would not reduce the amount of text in these books even though the teachers understood that all the information could not be contained. However, a picture is also worth a thousand words (see Chapter 7, Section 7.5). A large volume of information can be condensed with a picture, and, in addition to this, pictures offer additional positive benefits for learning (Alessandrini, 1984; Mason et al., 2013; Koedinger & Nathan, 2004) in terms of memory (Paivio, 1986) and recall (Levin & Mayer, 1993). How much text a student wants on a page is another gap in the literature addressed in the focus group discussions (see

Chapter 6, Section 6.3.3) along with the reduction in documentation size (see Chapter 7, Section 7.5).

Very few research papers on programming textbooks involve visual communication or design in their theoretical background. As will be discussed later in Chapter 4, noted computer science academics Paul Denning and Emeritus Professor Donald Knuth stated that computer science needs to be open to other fields as well as be available to a wide range of audiences (see Section 4.4.3). TOAOCP seeks to apply visual communication as a method to make programming information accessible while also appreciating the principles of Universal Design for Learning (UDL) (see Section 4.3.7).

Spiliotopoulou-Papantoniou et al. (2009) examined the visual internet representations in secondary schooling in Greece. These researchers prioritised visualisation to represent abstract topics, and the results highlighted problems in the student's interpretation of the visualisations. Their suggestions for further research included analysis of the visualisations. They also suggested an approach where the students analyse the instructor's use of the representations. The significance of the suggestions for TOAOCP was although visualisations are somewhat helpful for some of the students for understanding programming, they may not be the best method for assisting the recall of the individual algorithmic sequence occurring in the program. TOAOCP considered a limited number of 2-dimensional static pictures on a page to contrast to what is dominantly used in the computer programming industry to visually educate students, that are, programming textbooks and software visualisations (see Section 4.1.2). The limit may assist recalling information better.

According to Grover and Pea (2013) and Lye and Koh (2014), a fundamental problem within the communication of computer programming skills within high school is that that there is "... little evidence on the transfer effects of computer programming skills in the context of twenty-first century education" (Scherer, 2016, p. 1). One reason for this lack of reflexivity or deeper learning is that the programming curriculums used to teach adolescents in the past, may need to be redesigned. Despite the difference in the mediums, problems also occur in the digital realm that are also worthy of a visually designed solution.

The literature search concerning the state of programming tuition also involves the media the content is displayed irrespective of what that content is. Despite the proliferation of the graphical user interface (GUI), a tool designed to display pictures, an analysis of the effects of using pictures comparing different communication mediums to teach coding has not occurred. Fessakis, Gouli, and Mavroudi (2013) suggested an approach whereby new programming environments for children should be developed, and Mayer (2015) also supported more rigorous research beyond the description of the programming environments tools. Scherer (2016) contends that transfer effects of programming instruction must be systematically evaluated. A digital image solution may be what is needed in these contemporary programming environments.

TOAOCP examines the effects of placing the pictures first in the documentation. My research also draws from comic book theory as well as graphic and information design in the design of the programming documentation. Other studies do not evaluate programming documentation from these angles. In their article titled *Suggestions for content selection and presentation in high school computer textbooks*, Lin and Wu (2007) propose ways to choose what is included in high school computer textbooks and how this is presented. This Taiwanese study reviewed thirty-two textbooks analysing inadequacies and summarised them as follows:

- Wintel bias;
- Too much coverage of software application tools;
- Too little of computer science concepts;
- Too many technical terms;
- Meaningless analogies and examples;
- Lack of supplementary materials;
- Inadequate treatment of programming-related content.

Lin and Wu (2007) also found that lengthy discussion of irrelevant topics was inappropriate and that technical terms in text books were often used in excess and poorly defined. They raise the issue of facts being presented as fragments rather than within a system. Fun, a factor examined for its relationship to using pictures when learning computer programming in TOAOCP (see Section 6.1.5), is also claimed by Lin et al. when computer teaching methods that utilise pictures are used "... such as simulation or visualization tools" (p. 518). Fun, in Lin's article, is not directly linked to the use of images within the simulation or visualisation tools. The examination of the relationship between fun and the intent of the participants to learn programming through pictures was examined in TOAOCP (see Section 6.1.3). TOAOCP examined each factor of attitudes within learning, for its impact upon intent to learn programming through pictures as well as comics. For a full discussion of the impacts see Chapter 6.

Visual Basic (VB) is a programming language where a programmer creates an application using components on a drag and drop interface. The majority of high school computer teachers in Taiwan (72%) favour VB as the language of instruction because it is fun and easy to learn. The United States also favours VB in high school (Stephenson, 2000; Stephenson & West, 1998). Lin and Wu (2007) make the point that despite the popularity of VB as a preferred teaching language in these countries, the textbooks that communicate VB are unsatisfactory. The reason given for this poor communication is an over-emphasis on the GUI details at the expense of the "... programming basics" (p. 519). The success of a textbook for VB would be due to blending programming concepts into the "... visually appealing programming features" (p. 519). Visual realism was used in TOAOCP to combine code and picture (see Section 4.2.2) where Figure 4.22 and Figure 4.23 illustrate how pictures and text were combined for meaning-making.

FIGURE 4.3: MacPaint manual cover

At this stage within this literature review, it is worth noting some of the issues cited about documentation and communicating its use through a historical example. The public could use MacPaint in 1984 (see Figure 4.3). One manual (text) written for the MacPaint software used a different publishing model, where graphic designers worked alongside the engineering team from the beginning of the product development lifecycle. Employing graphic designers at the beginning of the software development lifecycle was radically different from the previous model. Here graphic designers worked alongside the engineering team. At the time the reviews about MacPaint highlighted the fact that the user interface, more specifically the iconology designed by Susan Kare was "... straightforward and intuitive" (Cates, n.d., p. 71), and had universal appeal (see Figure 4.4). The publishing model was altered to communicate to a graphic design audience who would be the 'user base' for MacPaint.

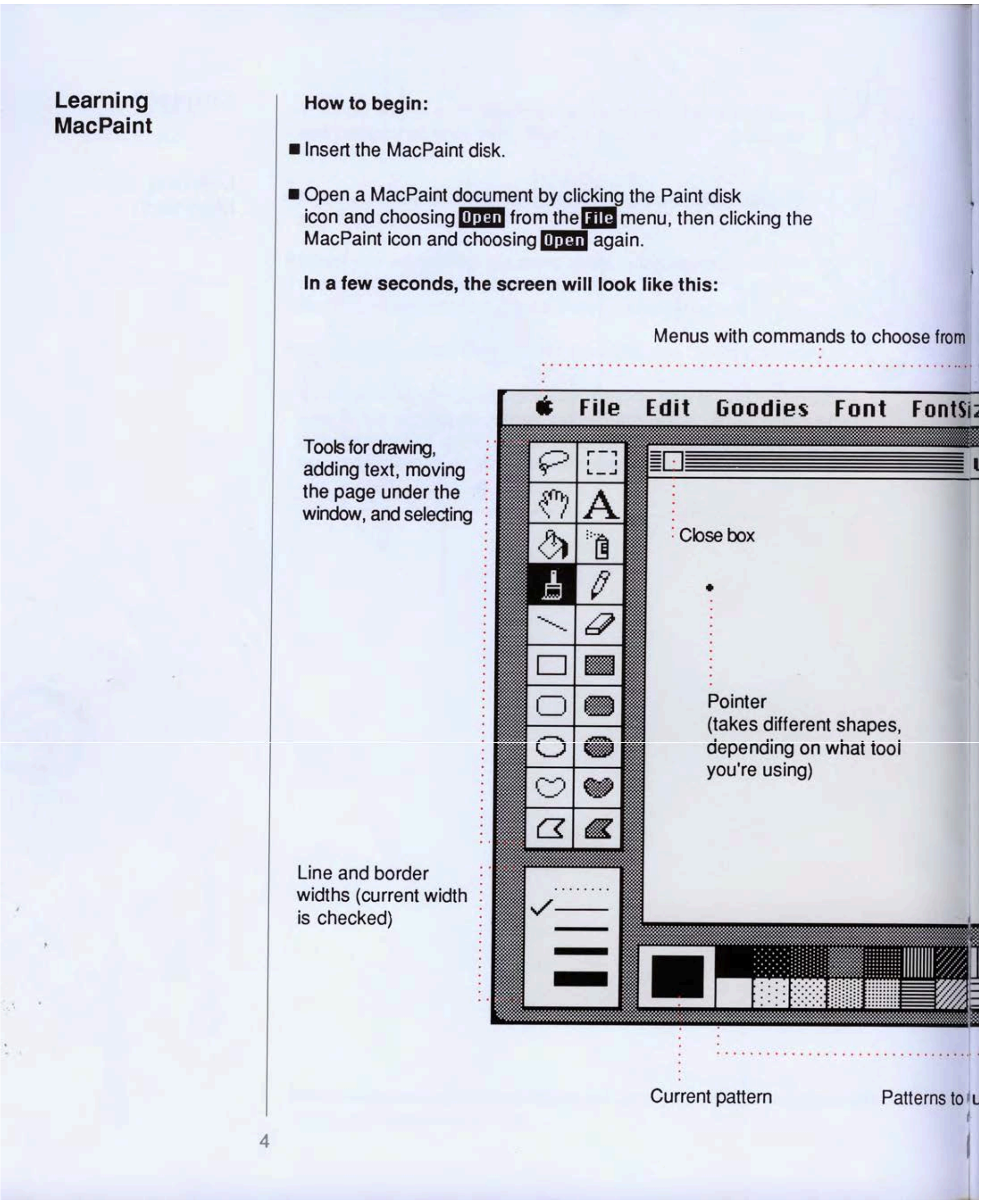

FIGURE 4.4: MacPaint 1984 manual p. 4

Users of the MacPaint manual and Macintosh system programmers both had different needs in terms of documentation requirements. The distinction between writing for the Macintosh system programmers and the MacPaint users was unique because different people were employed to fulfil diverse roles. MacPaint software manuals involved the creative services team comprised of artists and designers such as Clement Mok, who set a graphics standard for the original user manuals. Mok approached the design process from the point of view of the user, and he therefore positioned the MacPaint manual to embody clarity for the user. Mok prioritised communication through design, and the user base began to see computers as being almost 'friendly'. At this stage of writing the MacPaint manuals, the brief from Jobs was that they would be like a magazine. The manuals were to have a short amount of text, and graphic designers were to design the manuals.

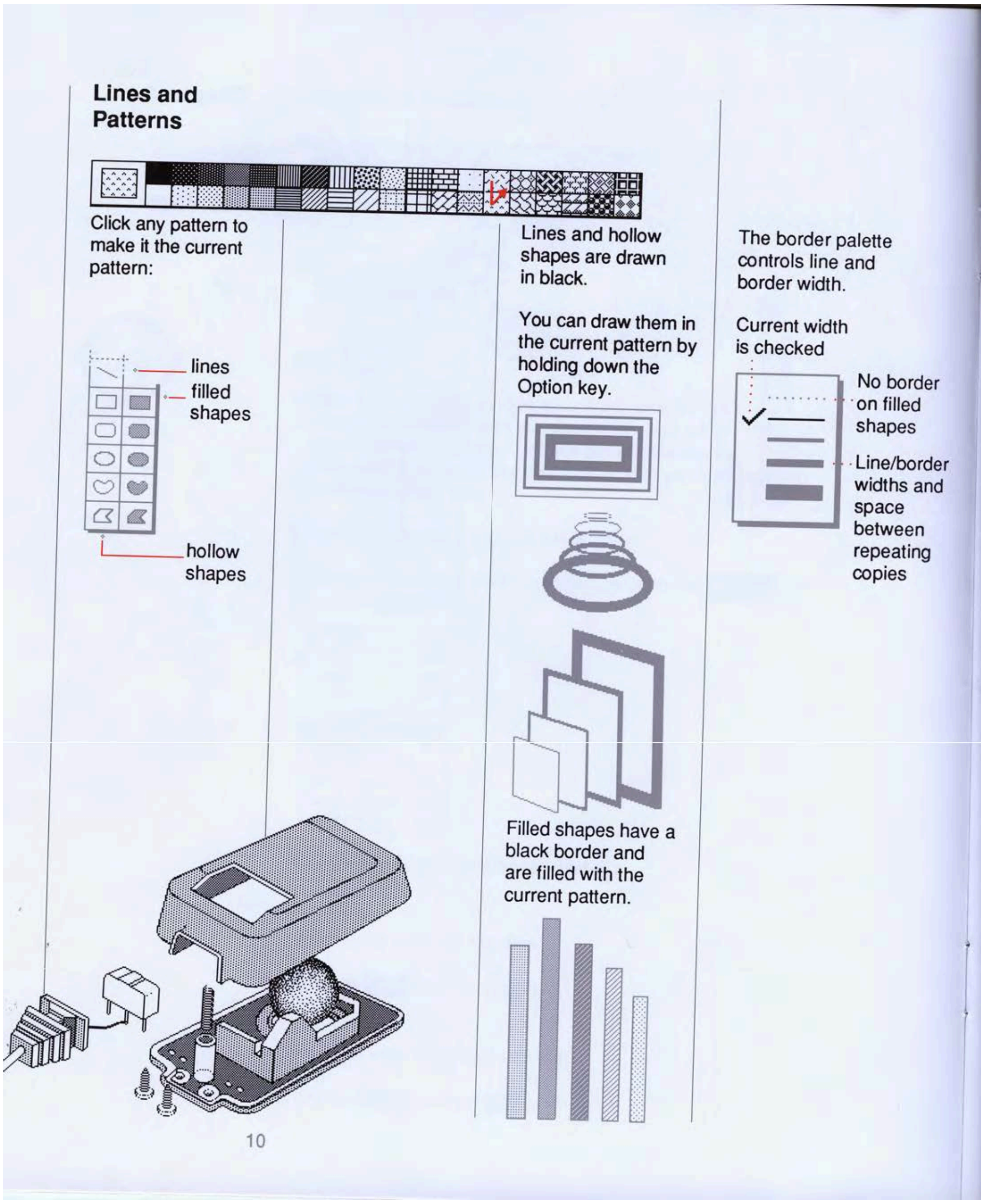

FIGURE 4.5: MacPaint 1984 manual p. 10

The designers influenced all areas of authorship including pictures, structure and type (see Figure 4.5). The MacPaint manual addressed three areas of learning through the structure of the book (see Figure 4.6). The first area concerned learning that involved gesture and the HCI. The second looked like a recipe book where a visual style of an algorithm would involve repetitive tasks. This recipe style section was time ordered from left to right within six columns. The third and last area was a summary of the tools, icon by icon. There were 'callouts' or information concerning tips that were designed to look different in this section (Section 4.1.2). Because of the budget allocated for the manuals, high-quality photographs of human models, as well as machines, were used. Photographs were expensive to print and conveyed an aesthetic purpose or high culture. Line art indicated visual instructions and communication. Arguments surfaced over the amount of text in the manual as the inventors of MacPaint stated that it was devoid of fun and did not promote exploration (Pang, 2000). At this stage, Bill Atkinson, the inventor of MacPaint rewrote the manual purely as a picture book. Another rewrite of the manual occurred later, as some software reviewers thought it too thin. At the time of MacPaint, manuals were products that rationalised the cost of software that could not be seen or held, and thus the thicker the manual was, the better.

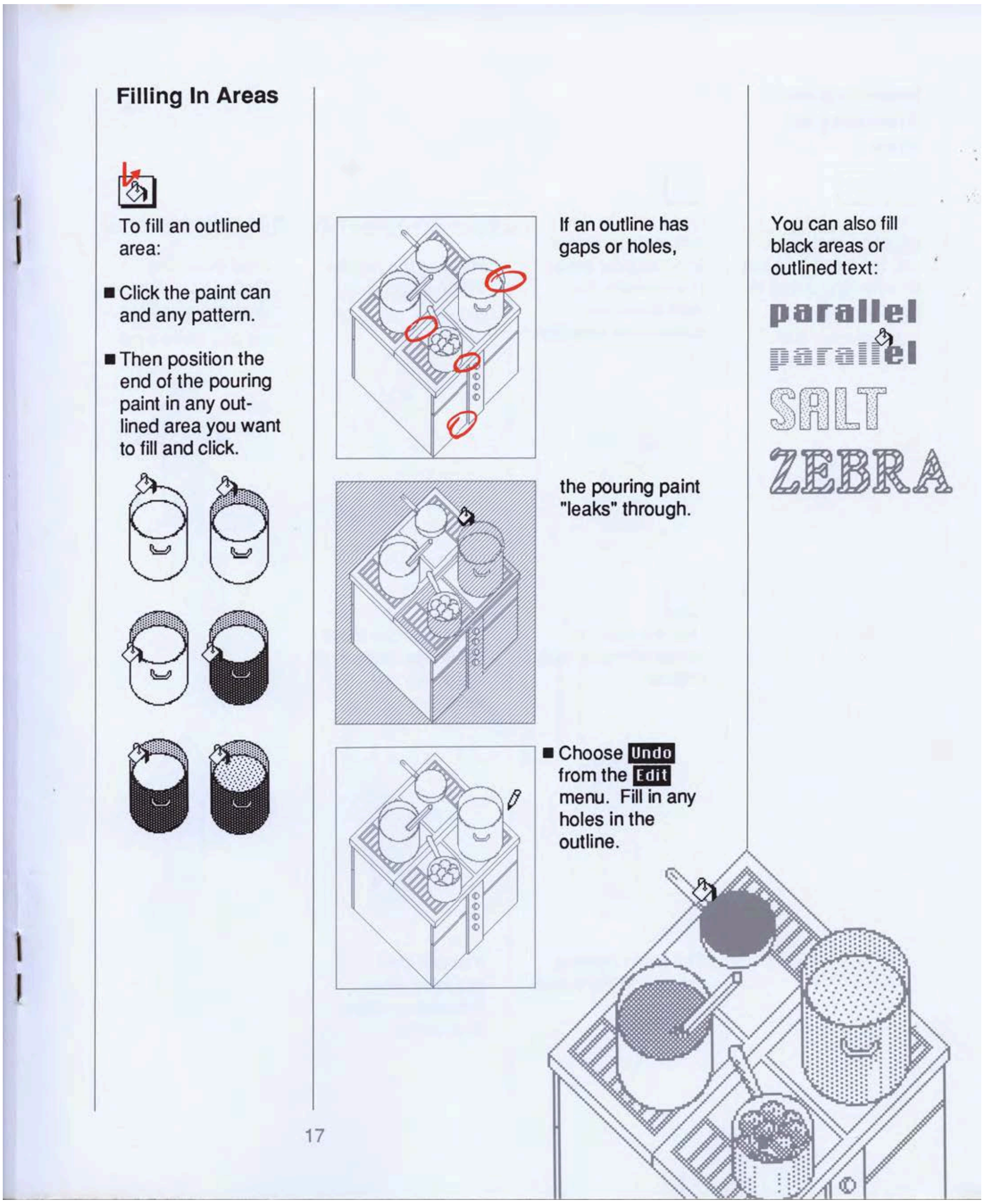

FIGURE 4.6: MacPaint 1984 manual p. 17

This brief case study on the early history of Macintosh documentation was raised in order to highlight communication issues between writers, designers and programmers when software is being documented. The publishing model that was used to record the MacPaint software was different from the existing documentation produced at the time because graphic designers began to work as part of the team from the beginning of the product development cycle. The frustration of designers when they are "... brought in too late within the product development lifecycle" is widely acknowledged (Buchanan, 2011, 34:27). This section has briefly covered some significant issues concerning the communication of computer software. The literature review now continues with a discussion of pictures, their definition and how they aid the process of communication.

4.2 A pictocentric approach - learning programming through pictures

This section discusses the relevance of pictures within the research. Figure 1.7 to Figure 1.13 have already given a general idea of how visual communication can represent programming for Year 8s. These figures formed part of the instrumentation (see Appendix A). Pictures as communication in learning and complexity are rarely addressed or studied. Many graphic design texts comprehensively discuss layout and type (Elam, 2001), however few discuss images and how to make them. Disparate evidence has been garnered from the areas of graphic design, instructional design, comic book theory, and visual realism to form this section of the literature review. These areas have been combined within TOAOCP to consider learning complexity through pictures first and were a pictocentric approach to communication.

The term 'picture' has been used interchangeably with the word 'image' by many scholars. Within seminal critical literature however, the two terms are treated separately. Pictures are a physical form of, for example drawing on a page or oil on canvas, or pixels on a screen (see Section 4.2). They possess varying complexity and levels of realism as noted by picture theorists as well as comic book artists (Gropper, 1963; Knowlton, 1966; Dwyer, 1979; Wileman, 1993; McCloud, 1993a; Medley, 2013a). One of the research aims within TOAOCP was to consider pictures for the value they offer besides the aesthetic. If pictures are used as a communication medium, it is necessary to leverage and understand how they are designed to inform before being aesthetically pleasing.

The picture creator takes into account many visual features when designing. Distillation is the process of removing detail from an image so that it appears less than real (McCloud, 1993b). Illustrations are often distilled from a photo. Pictures that are distilled can communicate more powerfully than their real versions (Medley, 2010). Distilled pictures have been used throughout TOAOCP for the purposes of clear communication. All the images created for TOAOCP describe programming concepts and ideas. The participants were mostly successful at understanding their meaning 6.2.1. Visual faculties such as perceptual constancies exist within the brain whereby what the eyes see is expected to be the simplest version of what exists schematically in memory before. Once the brain detects for example, picture signals from the eyes, the brain matches the signal to existing schema, if no match exists the schema is recreated and modified. Perceptual constancies are mental faculties that allow a less real object to represent a real object. Within constancies, shape, size and colour constancies reside. TOAOCP used these constancies in the pictures created, the Gestalt principles as well as caricature to communicate directly with the viewer, leverage visual perception and lastly to support memory within the learning process.

Designer, Nigel Holmes communicates in his book *Wordless Diagrams* by completely removing any text from pictures (Holmes, 2005a). The way in which the pictures are highly effective, is that they provide an instant delivery of information. Of course, a textual description could describe the process of pruning the rose in Figure 4.7 (Holmes, 2005b). However, the speed of the communication would be greatly lessened. Figure 4.7 contains pictures that represent a flower firstly on page 58, and then add the abstraction of a close-up part of that flower into which a red graphic on a 45-degree angle has been added. The line art drawing of the hand holding shears above the circular shaped abstraction of the cross-section of the flower is an instruction to the viewer to cut the stem at the required location.

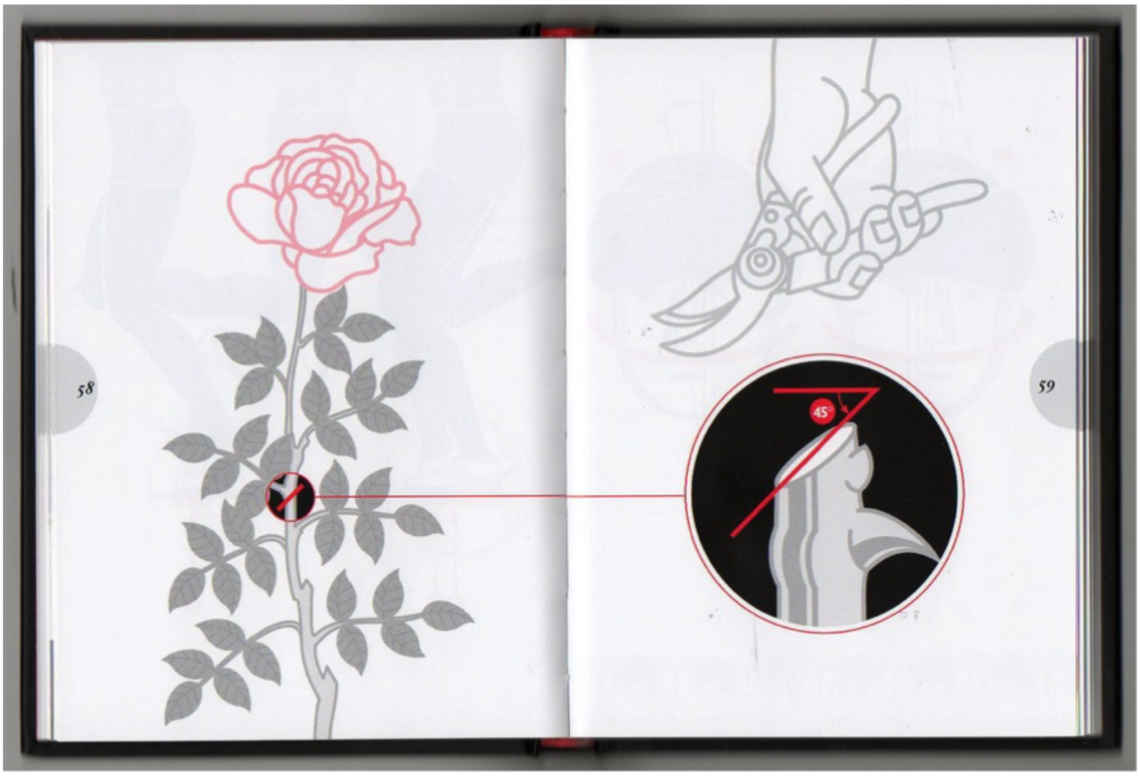

FIGURE 4.7: Excerpt from Wordless Diagrams, Holmes (2005), permission to use figure

In Figure 4.7, the large black circle represents an event in time. For example, the black circle above is a picture representing the event where the stem of the rose is cut. During the creative practice of TOAOCP, it was necessary to represent the total computer program as in the above Figure 4.7 where the entirety was on the left, and the precision or detail was then shown on the right (see Figure 4.13). This representation of the entirety on the left is also discussed further in the Gestalt principles (see Section 4.3.5). In visual perception, when time or sequence are represented, the natural track that the eye follows is horizontally from left across to the right. A gestalt is experienced or whole is first perceived and then the parts or detail follows as discussed further in Section 4.3.5. In western reading practice, the tradition or norm is to have the sequence and time progressing from left to right. In western cultures, the eyes track a path from left to right and then down the page (see Section 4.2.1). TOAOCP explores learning by placing picture and code together but still uses the western accepted order. Many of the pictures that illustrated the coding concepts in TOAOCP could not be seen in the real world (see Section 4.2.5). In order to explain the process of drawing things that cannot be seen, metaphor and analogy will be examined next.

Pictorial metaphor and analogy

Metaphor is a cognitive phenomenon that was first empirically supported by Seitz (1998). According to Seitz, metaphor can be recognised across different sensory domains and because of this recognition, metaphor can be synaesthetic. According to Kogan and Chadrow (1986), pictures tap perceptual process in children that arise prior to language.

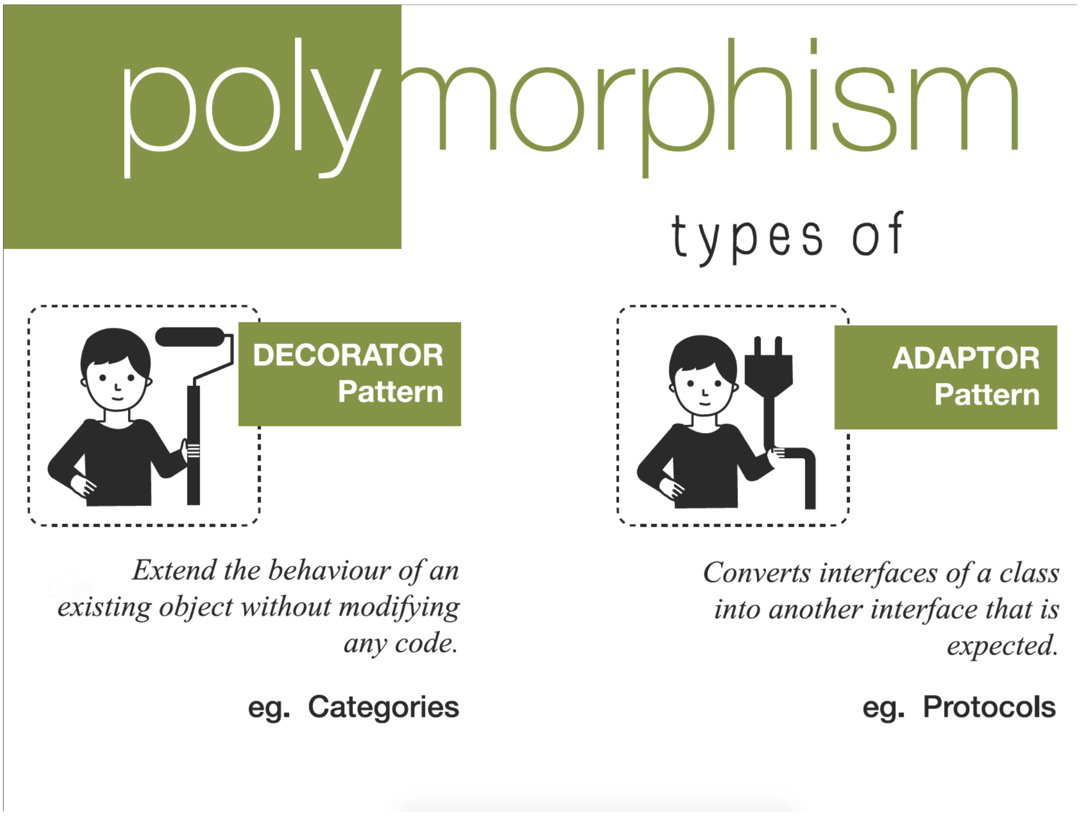

FIGURE 4.8: Decorator and adaptor design pattern metaphors

Metaphoric abilities have common origins and pictorial metaphors can convey abstract conceptual relationships (Kogan Chadrow, 1986, Kogan et al 1980, Seitz 1997a). Through pictures, understanding occurs as the picture is seen and applied through analogy to computation. For example, in Figure 4.8 the decorator pattern is implied by displaying a worker holding a paint tool. The design pattern pictograms were created to indicate when the pattern was being programmed. This abstract representation was needed within the milestones to represent the hierarchy of knowledge within computer programming. It is not always obvious to novices what part of a software design pattern is being programmed while intently copying lines of code. The decorator pictogram was created to serve as a grounding device to let a learner know they are programming a decorator pattern.

Pictorial metaphors were also used in TOAOCP for holistic purposes. Rather than keeping the brain activity of the learner functioning in the left hemisphere, the milestones were designed to alternate between left and right by providing picture metaphors and code together. According to Winner and Gardner (1977) the right hemisphere is crucial to processing aesthetic meaning and Goodglass and Butters (1988) suggest this hemisphere also comprehends complex patterns and images. In contrast to what the right side of the brain achieves, the left is excellent for recognition and comparing visual details (Farah, Gazzaniga, 1985). The next section deals with pictures in sequence and comic book theory and places particular emphasis on the advantages of learning complexity through comics.

4.2.1 Pictures in sequence and comic book theory

Comics are a popular choice for creating narratives, they are not predominantly focused on didactic goals or used within instructional texts. Nevertheless, comics emerged within TOAOCP as a tool that can possibly lessen cognitive load when learning programming. This is discussed further in the results section (see Chapter 6, Section 6.3.3). Comics assist in the creation of mental models in a step by step fashion through each picture symbol and this is discussed further on within the mental models section (see Section 4.3.2). An investigation into comics as imparting information through design now follows. Comics are:

> Juxtaposed pictorial and other images in deliberate sequence, intended to convey information and or to produce an aesthetic response in the viewer. (McCloud, 1993b, p. 9)

Like interaction designer, Bill Buxton, whose work is discussed later in Section 5.8.1, McCloud states the importance of the transitions between the panels in contrast to the look of the panel. In his book *Understanding Comics*, McCloud describes six panel-to-panel transitions (McCloud, 1993b). The first two transition types are moment-to-moment and action-to-action (see Figure 4.9). These two categories are time ordered, sequential and contain the same subject with an incremental or more than incremental progression. Up to this point, only these two transitions suited the comic panels I was creating for TOAOCP. As these comics were different from other types I had researched, and were aimed at imparting educational information I called them learning comics.

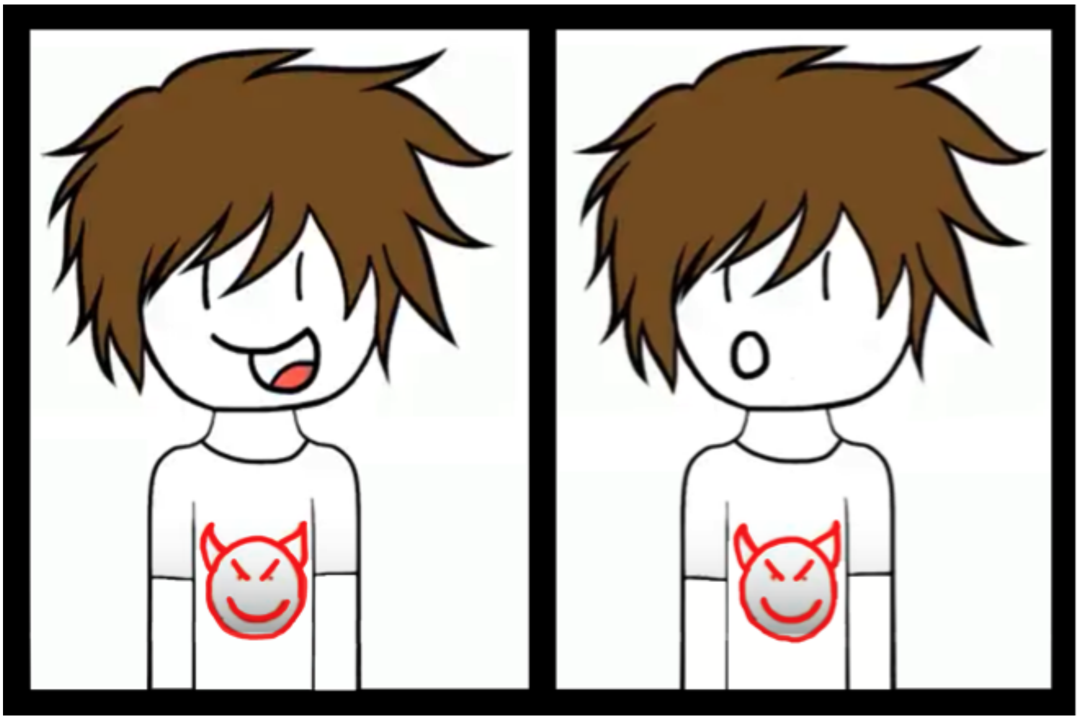

FIGURE 4.9: Panel-to-panel transition, Figure adapted with permission, Jai Tarr, Tarr (2017)

Figure 4.9 is an example of the first type of moment-to-moment transition. Although the instructive panels I generated were not directly equivalent to the type of narrative panels McCloud uses, I nonetheless used them as a guide throughout the thesis, while keeping in mind that narrative has a higher influence on this type of panel than the panels used in TOAOCP.

Cohn (2013) addresses the issue of pictures in sequence in terms of understanding in the article *Visual Narrative Structure*. Cohn cites McCloud (1993) and states that sequential images are found in a diverse range of places from the Stations of the Cross (see Figure 4.10) to airplane safety manuals. The sequential images in comics establish mental representations that promote understanding (Neil, 2013) and further, graphic marks are connected to "... conceptual structures that encode meaning in working and long-term memory" (Jackendof, 1977; Jackendoff, 1990).

FIGURE 4.10: The fourth panel from the Stations of the Cross

Another comic artist, Chris Ware, uses a sophisticated form of layout and panel arrangement within his comics. Ware's books and illustrations are an example of balancing sequence or order while achieving an aesthetic look with the entire page. This ability to achieve an architectural layout within a comic enables sophisticated visual narratives to emerge such as the one in Figure 4.11 (Ware, 2003).

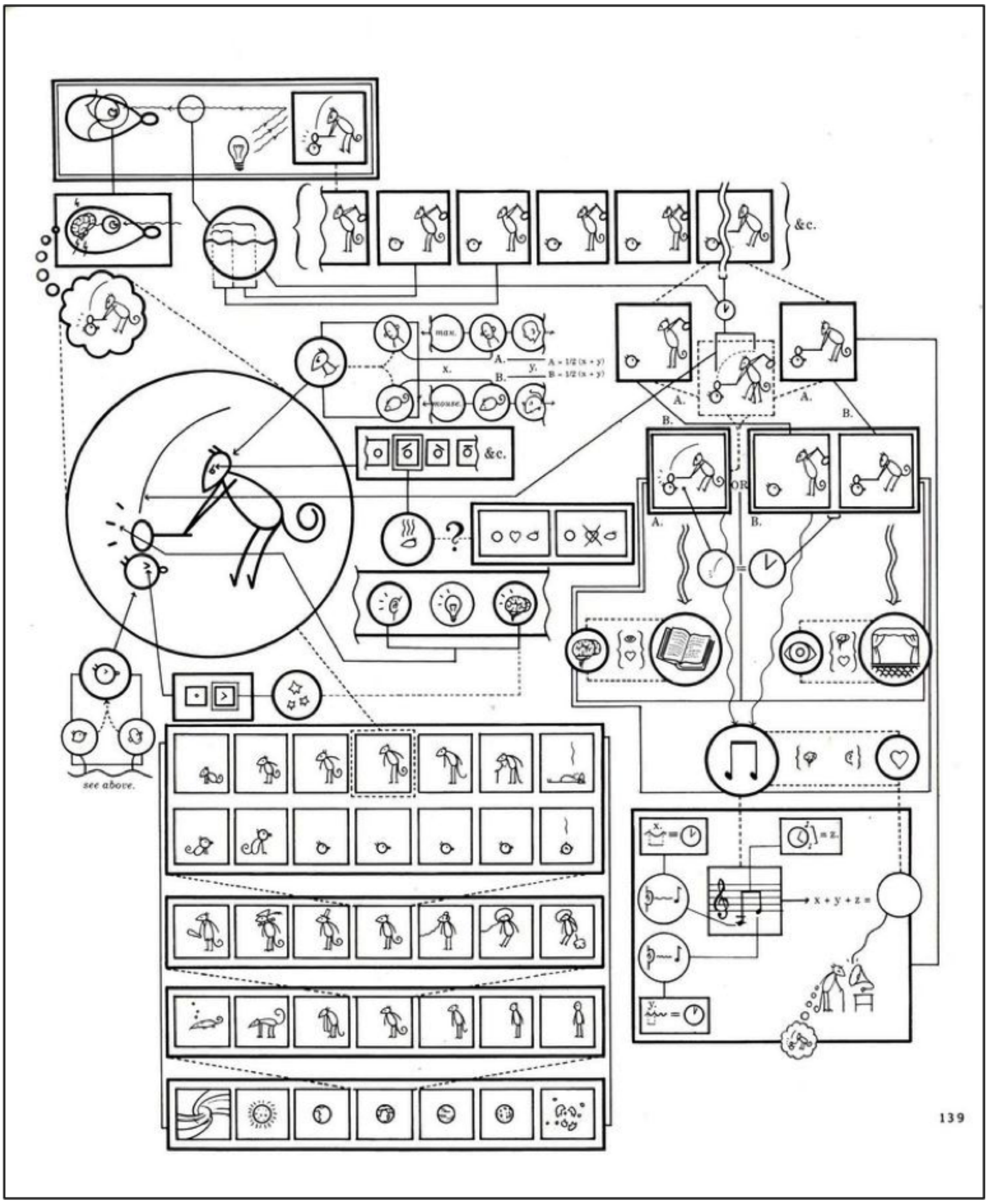

FIGURE 4.11: Quimby the mouse, Ware (2003), reprinted with permission

Quimby, the mouse, is the central character in Figure 4.11. By looking at the process that occurs to the characters we are 'drawn' through the creator's narrative or thought process. Each picture reveals a step in the overall construction of the event and each line of panels represents the processing of a state of information. The final state of representation is where the hammer connects with the head in the most prominent circle. Ware could have chosen any picture to go in the large circle. German philosopher, Gotthold Ephraim Lessing, states that a painter:

> . . . can use but a single moment of an action, and must therefore choose the

> most pregnant one, the one most suggestive of what has gone before and what is to follow. (Groensteen, 2007, p. 25)

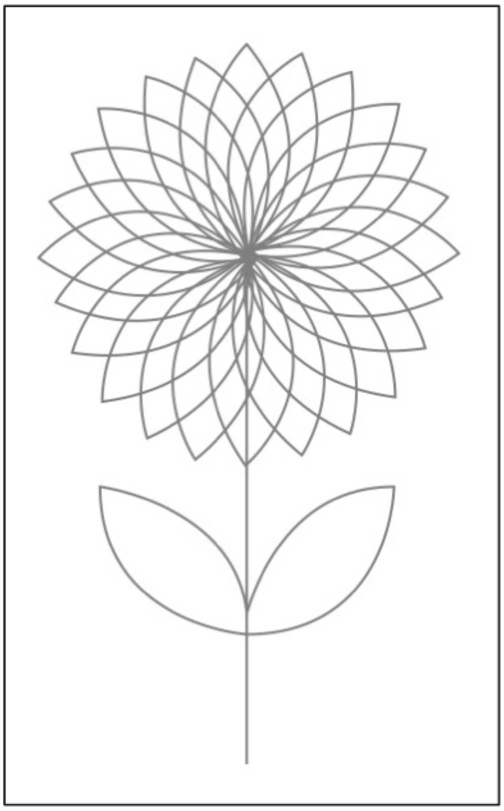

FIGURE 4.12: Final flower state

There are different picture themes within Figure 4.11 from the music notes to a stick figure sequence that resembles a form of theatre. The dotted lines guide the beholder's reading direction to give derived details concerning the focal picture. In the full example of the visual program to demonstrate the LOGO programming language (see Figure 4.13), the most pregnant panel (see Figure 4.12) is placed at the beginning of the page. The large picture (see Figure 4.12) is the final state of the program or the picture that results from executing the program, in contrast to images that are output to the screen as the program executes before.

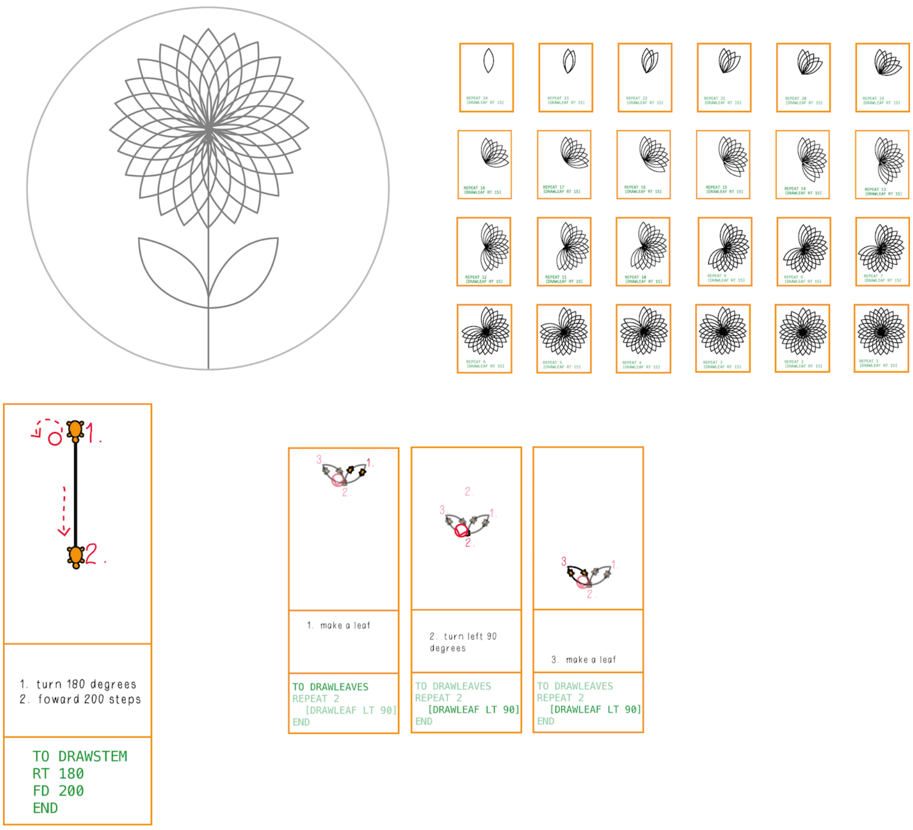

FIGURE 4.13: Full context of LOGO program and Gestalt example

Dotted lines expand an existing narrative or tangent to the proposed storyline. The five sets of panels on the left reveal a hierarchical structure (see Figure 4.13). For example, the lifetime of the mouse is shown over the course of seven panels. The specific time where the final state occurs connects to the series of panels that represent the mouse at various ages. If this panelling were an animation, it would not be clear at what age the mouse committed the crime. The images would disappear as soon as they appeared and a viewer's short-term memory may not be able to recall the information. Because the information is contained within pictures placed side by side, a valid conclusion is the mouse hit the head at precisely middle age (Groensteen, 2013). There exists strong academic arguments that comics support understanding and cognition within comic users (Foulsham et al., 2016a). There was a relationship found between the sequential presentation of the information and self-assessed cognition in TOAOCP (see Section 6.1.5). The arrangement of pictures in sequence make comics an ideal form for representing the execution of programming code.

Step by step, in each panel the fate of the mouse is revealed through the picture. Layouts like Figure 4.11 indicate to the viewer processing them that there are many layers and different types of information presented here. Comic artist Ware uses multiple levels and layers of complexity and abstraction. In the final circular shaped state, or critical panel in the comic, Quimby is hitting the cat's head with a mallet. David Ball's book, *The Comics of Chris Ware*, focuses on the diagrammatic devices used by Ware as well as on ideas about comics more generally. The idea of comics being a slow technology is presented by Ball and related back to the work of Jean Francois Lyotard and also concepts in the book *Chris Ware and the Pursuit of Slowness* by Georgiana Banita (Banita, 2010). Banita (2010) attends to comics as controlling pace or a tool that obstructs the "...frenetic temporality of consumer culture" (Banita, 2010, p. 177) while Ball and Kuhlman (2010) contends that:

> A reading of slowness in Ware's comics would not only give a new cast to what we consider to be the speed of comics as a medium, or the rhythm of its unique language, but also establish the slowness of graphic narrative as an essential parameter of making and reading comics. (Ball & Kuhlman, 2010, p. 177)

The ability of picture arrangements within comics to support the temporal organisation, or schema, in the brain is commented on by Ball et al., further stating; "This exceedingly meticulous creative process inevitably results in comics that may indeed be read very quickly but more often than not invite an equally painstaking approach on several temporal levels" (Ball & Kuhlman, 2010, p. 275). Ball et al., also highlights the idea of structure within the comic when he comments on the temporality of Ware's comics. Temporality, in the context of comic theory, relates to time or the picture or pictures drawn that depict time.

While Groensteen promotes the idea that "... a single image can imply or evoke a story it does not tell one" (Groensteen, 2007, p. 23). It is only the juxtaposition of images that creates a narrative. As with Ware's zoetrope, that is a device that was reused to cue or reuse an idea, Groensteen highlights the idea of order and waystages in Wendy Steiner's work. Steiner is quick to define her use of narrative as 'visual narrative', contending that it is the repetition of a subject that informs the story. She also acknowledges that a single scene can be a 'pregnant moment' containing temporal sequences. Stories containing meaning can be condensed to a "... single synthetic scene" (Groensteen, 2007, p. 24). These factors are not dissimilar to those measured in TOAOCP (see Section 5.5); however, they are namely presented as clarity, self-assessed cognition and strategy.

It would appear that understanding, or cognition, has more than one variable where a picture or pictures are concerned. Meaning is more complicated than cause and effect when it is expressed through visual communication. The complex model of cognition and pictures is outside the scope of TOAOCP. However, the impacts of rhetorical affects are not ruled out for future directions in research. Both Marin and Groensteen conclude that the arrangement of figures in space reveals logic within the scene being depicted and enriches its meaning. Within TOAOCP, these types of arrangements are crucial to the logical sequence of computer programming and are directly measurable as units.

Painter Nicolas Poussin used a classical French Baroque style in the 1600s placing importance upon clarity, logic and order. Poussin, according to Groensteen, increased density and complexity of crucial moments to highlight them and also considered hierarchy and organisation as components that are 'intelligible and essential'. These two terms are synonymous to meaning-making and cognition.

Pousin's strength as a painter was his ability to tell a story through his pictures. Different visual elements within his pictures were enhanced to support narrative. Figure 4.14 is a painting that recounts how Romulus the king of Rome wanted wives for his soldiers and sent them to kidnap women from the Sabine area in Italy. The painting in Figure 4.14 depicts torment and violence between the fathers and husbands of the Sabine women. The story about the Sabine women and their kidnapping was well known at the time Poussin painted the picture.

FIGURE 4.14: The rape of the Sabine women, Pousin (1638)

Groensteen also highlights the use of prior knowledge in Poussin's work. Prior knowledge is measured in TOAOCP (see Chapter 5, Section 5.5). The understanding of Poussin's picture is assisted by the viewer's existing knowledge. Knowledge enhanced from what already exists in a viewers mind, differs to the aquisition of new or undiscovered knowledge. The memory of the viewer recalls the sequence of pictures before and after Poussin's picture. The picture is only one point in a series. According to Groensteen, the understanding of Poussin's pictures is dependent upon prior knowledge of the story that the image manifests.

The multilinearity in Ware's picture (see Figure 4.11) is inspirational for any learning designer. Within TOAOCP, both picture and code were combined to explain programming instruction. What Ware's comic helped me to understand in the creative practice of TOAOCP (see Figure 4.51) was the multiple levels of abstraction of different ideas. The panel flexibility that combined music, astronomy, maths formulae and other topics draws a learner in and is an exercise in visual persuasion to understand complexity.

Aside from Ware's example, Groensteen makes a theoretical case for the comic structure as an exploration of new form and adds that it may be disruptive for traditional comic readers (Groensteen, 2007). He also hints that a new readership for comics may not yet have been engaging with the medium, as comic layouts and structures are still largely experimental. The data collection undertaken in TOAOCP when analysed, implied the arrangement of the pictures also played a part in the viewers understanding (see Section 4.5.4).

Comic books are gaining popularity in science and engineering for their ease of use. Information used in science and engineering is sometimes represented as a comic system that employs dual coding where both image and text are displayed together see Figure 4.15 (Pulé, 2014a; Borkin et al., 2013; De Almeida, 2009; Dousay, 2015; Heller & Vienne, 2012; Mayer et al., 2005a; Pulé, 2014b, 2006a; Pulé & McCardle, 2010).

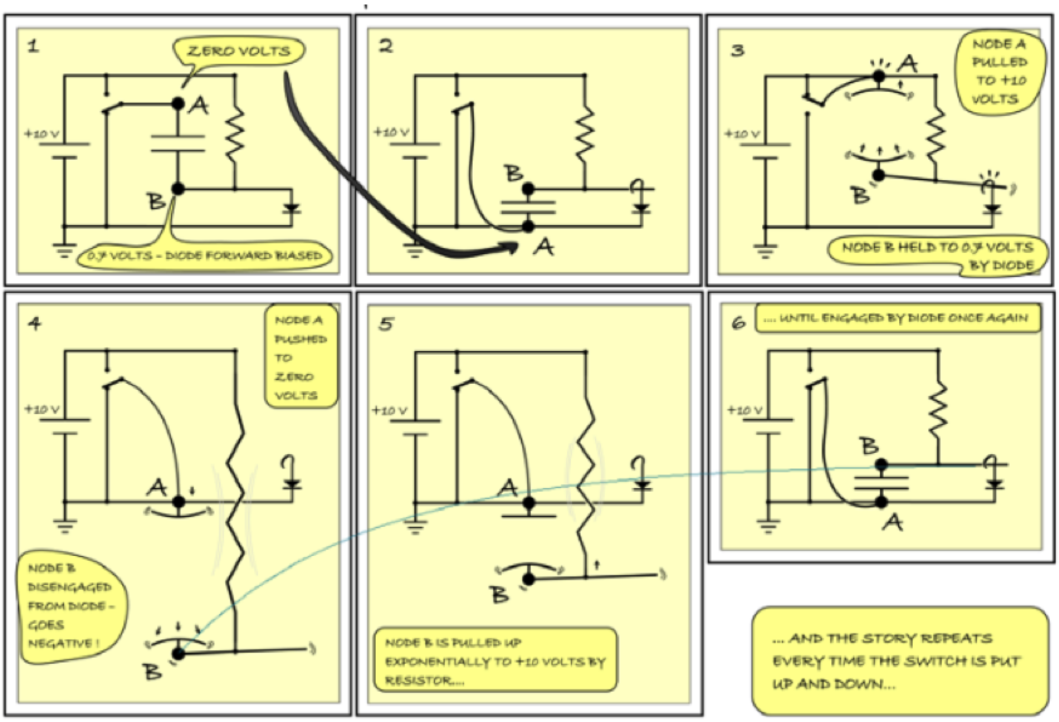

FIGURE 4.15: Dual coding used in engineering classes, Pulé (2014), permission to use figure

Scott McCloud maintains that learning material is advantageous for students when presented in a comic book form. McCloud (2015) lists the points below as advantages learning materials have in comics form. These advantages are:

- Pacing: When someone creates a comic, there are an optimum number of panels that suit the delivery of the information and the panel sequence must feel right. The decision of how many panels to include is based on what the story requires. Pacing in TOAOCP was determined by lines of programming code.
- Dynamic Range: Sizes and shapes of panels are determined by the comic designer and vary according to the dramatic effect required.
- Distance=Time: Comic creators have often restricted panel distance in order to save paper. As time and space can be represented digitally, panels featuring actions that are represented as slow can be drawn further apart.
- Flow: Breaks in a story can be customised to parts in the narrative by the designer. In traditional comics, the page determines the flow of the story.
- The Z-axis: This feature is digitally specific and makes a comic continuous through hyperlink. McCloud adds that although the Z-axis is at first a novelty, it essential has a practical purpose. The Z-axis could be particularly useful within a programming curriculum to access a topic across multiple lessons, for example, if a pattern occurs in one place, when it re-occurs both patterns could be joined by this axis.
- Identity: McCloud states that comics are an artform first, irrespective of new technology that is introduced. Here, he is referring to the fact that pictures are the first elements created in a comic. McCloud again states that if you add images to the story (here he means text) that you begin at a deficit (Kuriyama, 2018).

As a result of examining these points, measures for flow were added to the evaluation section of the instrumentation and it did end up having an impact on cognition (see Chapter 6, Section 6.1.8). Norman (1993) in his book *Things that make us smarter*, offers a clear definition of 'flow' explaining that "The most efficient working experience occurs when one is in a continual flow of focused concentration: absorption in an activity. . . " (p. 35). Flow, in a learning context, was initially researched by Csikszentmihalyi and refers to a feeling of being fully immersed in an activity (a more detailed explanation is given in Section 4.3.6). Groensteen (2007) explains flow in the context of comics from the perspective of modalities within his descriptive framework. He states there are four modalities (spatial complementarity, perpetuation, rhythm and configuration) that can exist before the reader's eyes when viewing a comic. These modalities build upon Csikszentmihalyi's concept of flow in that they are specific to comic media.

The perpetuation mode of looking at a comic by an individual occurs before any semantic processing (Groensteen, 2013). Researchers have connected flow theory and the medium of comics before (Davies, 2017) however the benefits of designing picture sequences within a comic, and how this design impacts on the flow state of a student when learning, is yet to occur. As discussed Norman attributes being in flow to focus and holding concentration. Flow is also a characteristic of aforementioned perpetuation mode.

Although not directly referring to Flow Theory in the following quote, Groensteen's view on the flow of images and comics is detailed:

> The flow of images, which catches the attention of the reader and vectorizes his/her eye movements, continues without interruption; it just keeps going. If this flow produces meaning, then its perpetuation sets up expectations. It promises new twists and indicates that the discursive activity of the images will follow its course until it reaches some kind of conclusion. (Groensteen, 2013, p. 34)

A rare account of flow and its connection to graphic design was conducted by web designer Jim Ramsey (Ramsey, 2007). The perspective of flow in Ramsey's article, *Designing For Flow*, is attributed to its inventor, Mihaly Csikszentmihalyi (see Section 4.3.6). According to Ramsey, flow is:

> ... that feeling of complete absorption when you're engaged in something you love to do without being disrupted by anxiety or boredom caused by tasks that are confusing, repetitive or overly taxing. (Ramsey, 2007, p. 1)

Ramsey further believes that flow is "... exactly the feeling we hope to promote in the people who use our sites" (Ramsey, 2007).

There are numerous reasons why the delivery of computer science learning materials benefits from a comic style of presentation besides flow. The hypotheses, stated in Section 5.2, focus on the delivery of visual information through a comic book layout and are measured through the quantitative methods in Research Phase Two.

The Z-path
The Z-path is the pattern that the eyes follow when reading a piece of text. This pattern also typically occurs when looking at a series of pictures in sequence that occupy more than one horizontal line. Cohn and Campbell explain the following about the Z-path:

> When forced to choose, readers typically prefer to order page layouts using a left-to-right and top-to-bottom strategy that maintains the 'Z-path' of reading inherited from writing systems, even when those comic pages have no content in the panels. (Foulsham et al., 2016b, p. 30)

The pages designed within the learning comic for TOAOCP were to follow the Z-path as much as possible, in contrast to the vertical listing of code often given to novice programmers.

Knowledge transfer and picture sequences
Current research on knowledge transfer from using comics is positive, but mostly does not include statistical data in its findings. Linguist Joshua Caldwell (2012) believes that there is a lack of research on the effectiveness of knowledge transfer within comics and contends: "There appears to be a paucity of studies which validate that comics, by having more visual elements, are more effective than text-only materials (Caldwell, 2012).

TABLE 4.1: Visual rhetoric and rhetorical convergence in comics

Structure	Form	TOAOCP Example
Variable	Purpose	
Size	Communicates quantitative variation	Milestone one
Shape	Expresses identity, differences and similarity	
Value	Relation, order and relative difference	
Color	Difference	Each Milestone has a specific colour
Texture	Relation, order and differences	
Position	Difference in sign in relation to axis	
Orientation	Expresses differences	

Caldwell additionally states that while the social impacts of comics are research worthy, their ability to transfer knowledge is also important. The knowledge transfer is discussed in his article *Information comics: An overview* and related back to the structure and 'Peircean' visual design perspective (Caldwell, 2012).

Information comics are comics that educate and inform to teach a student something. Professor Heike Jungst is a German translation scientist whose PhD focused on information comics. She notes how unfortunate it is that "... there are hardly any statistically representative studies on the effect information comics have on learning" (Jungst, 2007, p. 63).

These two characteristics (knowedge transfer and picture sequences) are not always achieved in studies on comics (Dolan & Rouen, 2003). Other studies that focus on knowledge transfer do so from the discipline of English (Lamanno, 2007; Yang, 2008; Cohn, 2012) and more specifically through the narrative within the comic. Studies on successful knowledge transfer and comics concern a wide range of disciplines from marketing and business (Azman et al., 2016), human factors (Bach et al., 2016), to health (McNicol, 2017), to information technology (Azman et al., 2015), to visual storytelling and science (Day et al., 2016). The comics used in the preceding section (see Section 4.2.1) are concerned with knowledge transfer with authors Caldwell (2012); and Jungst (2007) recognising the paucity of research into comics and knowledge transfer. Azman et al. (2016) found that participants agreed that comics could assist with technical and scientific content. Claims of comics supporting comprehension are acknowledged in other recent studies (Mallia, 2007a; Recine, 2013; Yildirim, 2013; Mehlmann et al., 2017).

Comic book theory was one approach I examined to create the practical components within TOAOCP (see Appendix A). This approach, with an emphasis on the pictures within the comics, is the difference between other studies emerging that examine comics.

It is hoped that my work can be used to generate changes in attitudes towards learning complexity across disciplines through using a picture based approach. The complex comics designs in TOAOCP contained distilled pictures that have a level of realism. The next section in the literature review addresses the role that visual realism played in TOAOCP.

4.2.2 Visual realism

Visual realism in this thesis refers to the capacity of a designer to reduce the amount of detail within a picture. For example, a photograph would be classified as a highly realistic picture (see Figure 4.16) while a line art illustration would be a picture that had reduced realism (see Figure 4.18). Within this thesis, learning concepts from a distilled picture rather than a photograph were tested by measuring a number of factors before and after. There exist categories of realism that produce different effects on the viewer.

FIGURE 4.16: Photograph of the side profile of a head

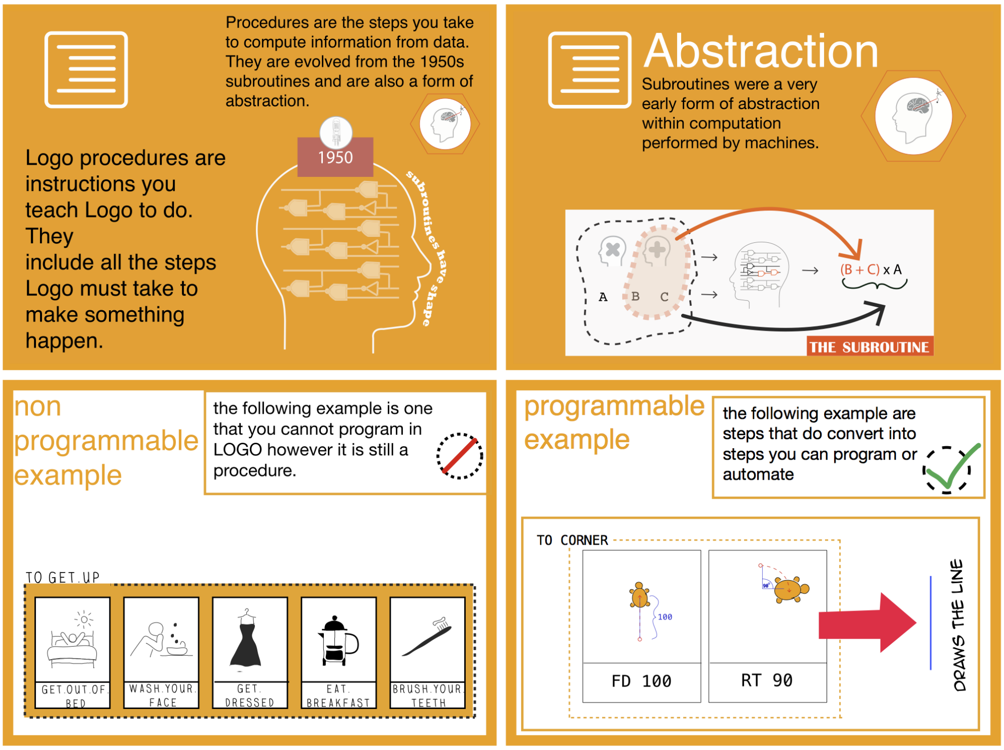

FIGURE 4.17: Less realistic pictures used to illustrate LOGO, milestone two

When I talk about distilled pictures in TOAOCP, I am referring to the way that the details have been made less than those in reality. Distilled pictures appear simpler and have fewer details upon the surface than their more realistic counterparts and are referred to as less realistic. Distilling a picture to make it simpler is a technique explicitly used when creating line art. Theorists recognise the technique for clear communication. Within TOAOCP the pictures were distilled to line art from reality for clarity. Pictures can be created in a range of styles from realistic to distilled and be categorised along a continuum.

FIGURE 4.18: Line art, head

The realism continuum is a way to classify pictures in graphic design. A definition of this type of continuum is a "... visual model that presents any image as a series of pictures, each iteratively reduced in fidelity from its referent" (Medley, 2013a, p. 23). The continuum has been used occassionally in the history of visual communication to measure the effectiveness of educational instruction. It also stands apart from the traditional semiotic analysis of pictures that dominates design history and critical theory. The perceptual approach to image making is thinly documented in comparison to the semiotic approach addressed by theorists such as Berger (1974) and Kress and Van Leeuwen (1996). The few works on graphic design that address realism reduction and theory come from gestalt psychology and sociology. Within TOAOCP the images were constructed firstly according to what is innate in human visual perception and the second way of construction was what was learnt and interpreted. TOAOCP does not intricately examine pictures through semiotics as many design and critical theorists have thoroughly done this (Barthes, 1977; Berger, 1974; Kress & Van Leeuwen, 1996). Table 4.2 gives examples of different types of realism pictures can have. Information becomes clearer to the beholder when a specific level of realism is adopted within a picture. Within TOAOCP the realism level was line art (see Level 3, Table 4.2) which, have specific appeal to adolescents and, according to Medley (2013b), hit a "... cognitive sweet spot" (p. 130).

A reduction in realism to more abstract representation has definite advantages for education in the communication of complexity. The realism levels were chosen for TOAOCP

TABLE 4.2: Realism level examples in TOAOCP

Picture type Uses	**Realism level**	**Example**
1	1-Photograph	Figure 4.21
2	2-Silhouette	Figure 4.21
3	3-Line art	Figure 4.21
4	4-Image related graphic	Figure 5.7
5	5 Arbitrary graphic	Figure 4.18
6	6-Description	Code listing in Figure 4.22
		Figure 4.21

to assist in adolescent learning and may therefore have a relationship to the topology of device design raised in the preceding section. There is a difference in meaning for each level of realism and the communication required (see Figure 4.21). By including a measure of different levels of realism throughout the curriculum, a lesson seeks to be holistic in that many different perspectives are expressed with pictures and retained in the learner's memory. For example, an abstract picture can be used as a device to encourage recall (Lansdale, 1988; Meier & Elsweiler, 2016). The model view controller (MVC) design pattern icon set (see Chapter 5, Figure 5.7) is an example of recurring themes throughout Milestone Six (see Appendix A). By using different types of realism through the pictures in TOAOCP, different levels of information could be referred to on the one page. For example, if a design pattern (see Figure 5.7) was present in the coding information on the page, I also included the associated pictogram with the design pattern coding instructions (see Figure 5.17). The same process was repeated with the view and controller programming and with the view and controller icons.

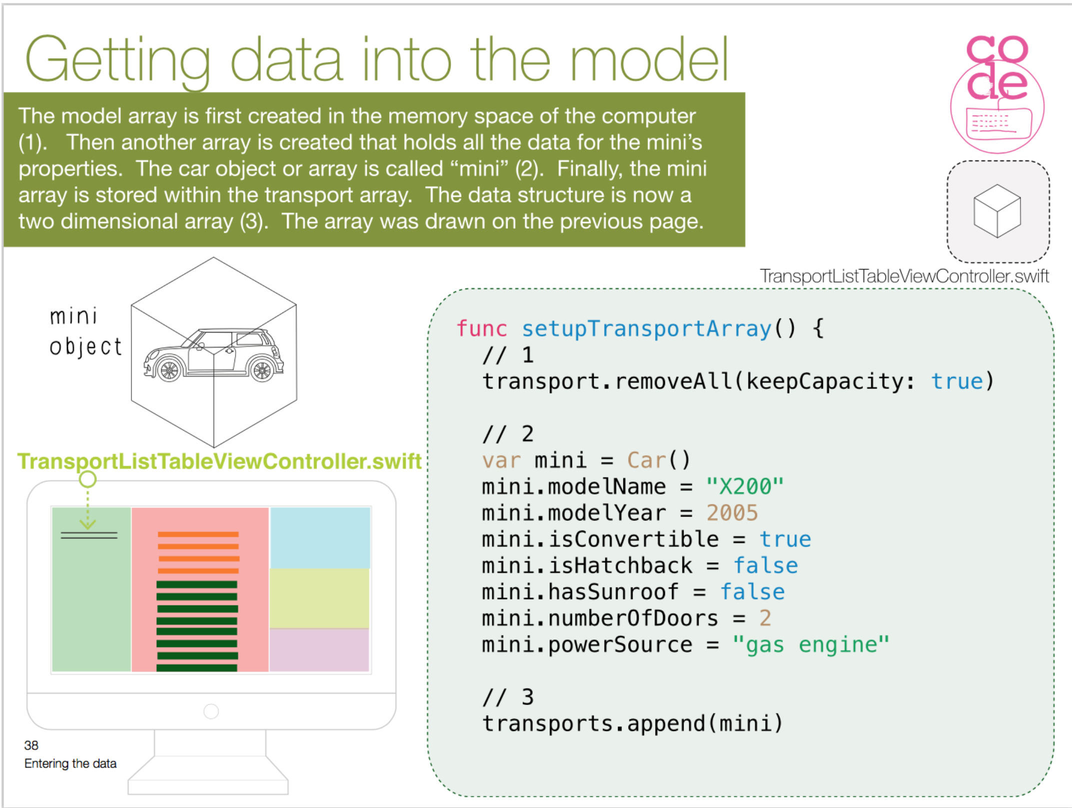

FIGURE 4.19: Milestone six, MVC with code

When creating the milestones for TOAOCP, the metaphor was chosen for the picture and then the picture was distilled (see Figure 4.20). This distilled essence took the form of line art because according to Alessandrini (1984):

> Dwyer concluded that simple line drawings are most helpful to learners while overly concrete or detailed visuals, such as photographs, do not aid learning. (p. 66)

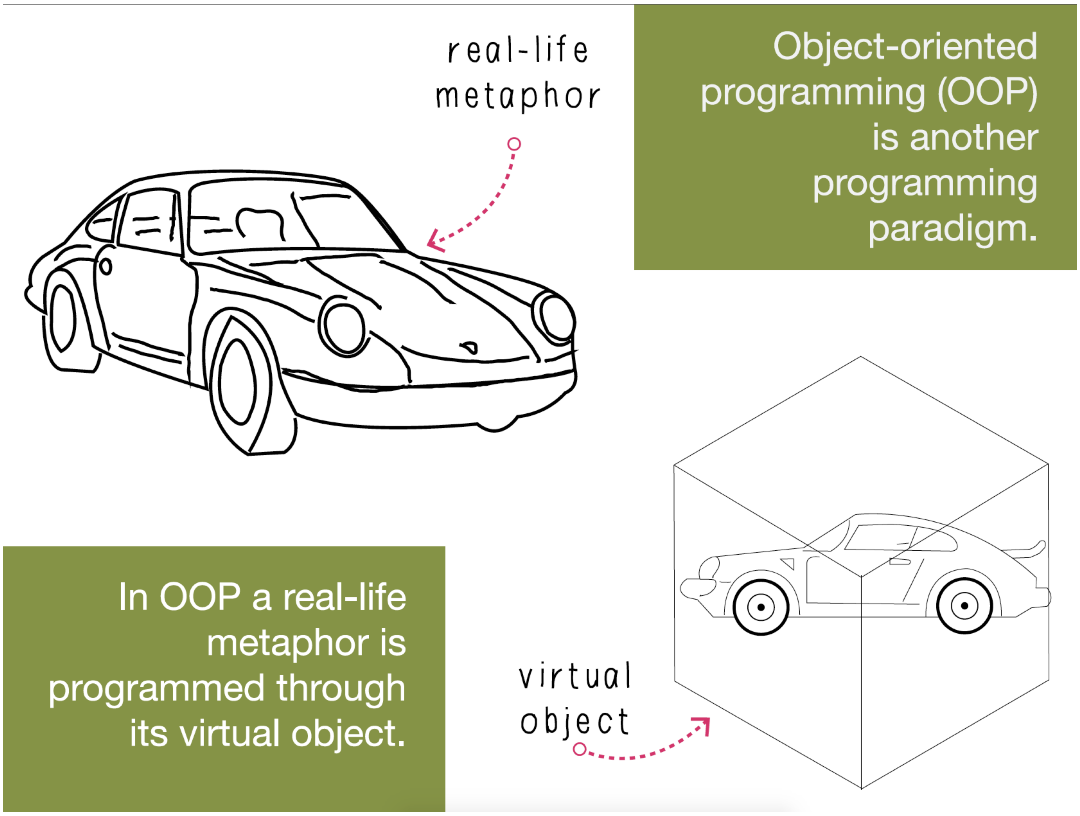

FIGURE 4.20: Milestone six, line art

The support from academic theorists for the use of distilled pictures in learning comes from many sources and is garnering momentum. I created the milestones (see Appendix A) to test the affects of learning through distilled pictures. E-learning designer Connie Malamed states that there are cognitive advantages to using low-fidelity graphics. These graphics allow quick visual scanning that in turn requires less information processing for brain activities such as instructions (Malamed, 2011). A "... reduction in realism forces a search for deeper meaning in the information presented " according to Medley (2013b) who also contends that line-art hits a "... cognitive sweet-spot " (p. 130). As early as 1978 Fussel and Haaland realised that for learning purposes "... line drawings perform better in this regard than photographs of the same things" Fussel and Haaland (1978).

FIGURE 4.21: Realism continuum, Figure adapted with permission, Lilybelle Tarr, 2018

In Figure 4.22, the picture indicates that the code is creating a convertible feature for the car. The code creates a space in computer memory that records that the convertible feature exists for the car object. I attempted to make the car (or picture object) equivalent to the code by encasing them both within a tiered panel. The purpose of the placement was to persuade an individual that they are equivalent in different systems. I attempted to equate the different communication modes to help the eyes first identify what was being coded and then provide the code for the brain to interpret (see Figure 4.23).

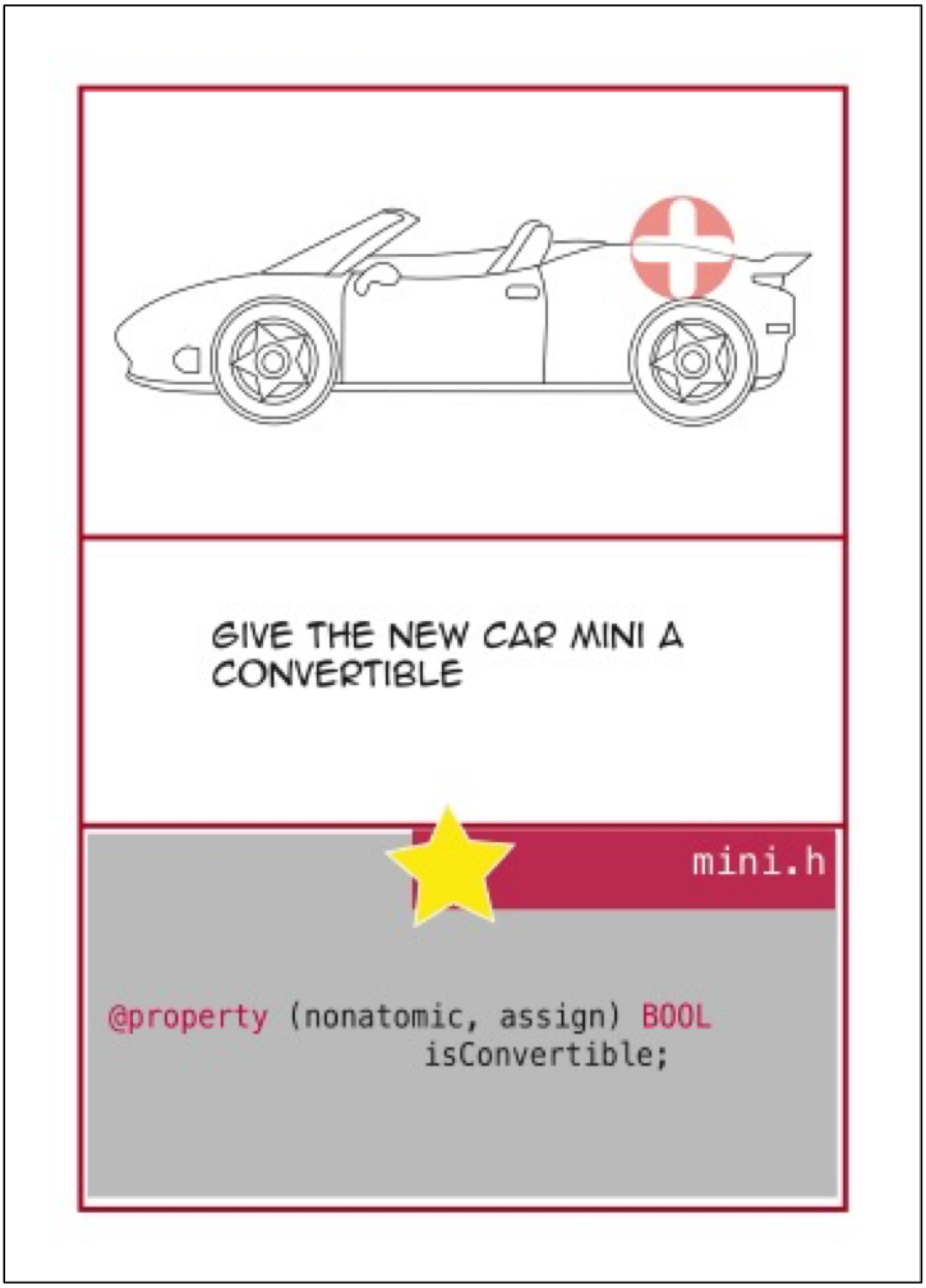

FIGURE 4.22: Comic panel

The object-oriented paradigm is ideal for combining these two different levels of realism. For TOAOCP programming is classified as an abstract level of realism, and it is this combination that is missing from many programming texts.

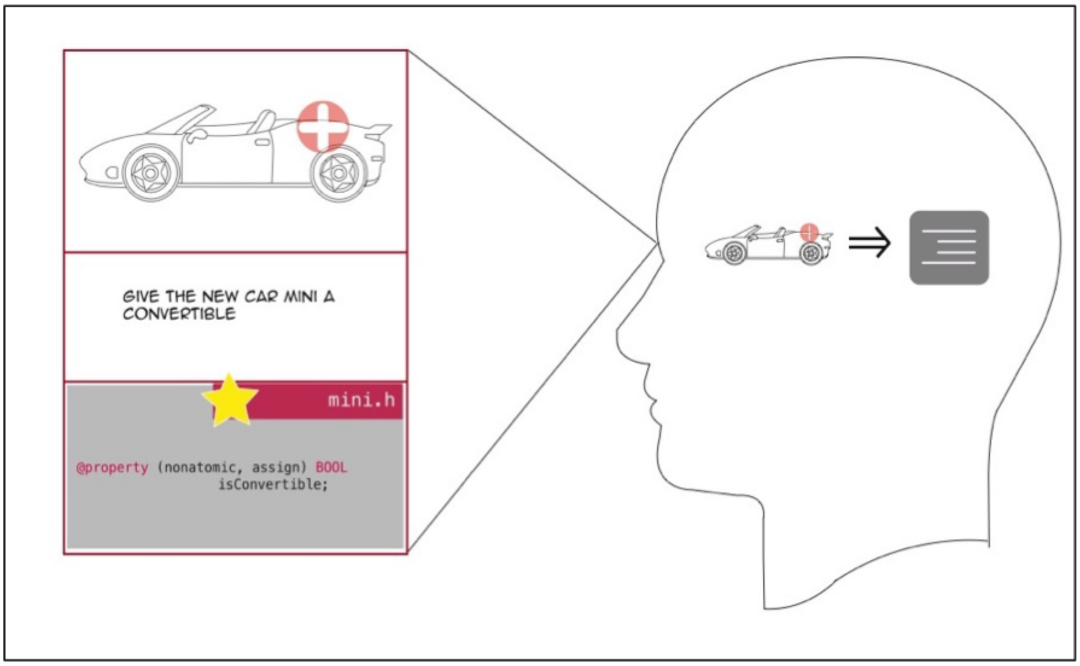

FIGURE 4.23: Dual levels of realism

Dual coding is a visual analogy where different levels of realism of visual and verbal form are matched in order to extend learning. This concept originated in 1971 by Allan Paivio and is a theory of cognition. Here the formation of mental images aids learning (Reed, 2010). Within TOAOCP the space on the page is a panel containing two or more panes (see Figure 4.22). The third type of vision is the ability of an individual to visualise something that cannot be seen in the real world (see Section 4.2.5). Analogies are devices used in computer science often to explain the third type of vision. For example, the Turing machine is a mathematical model. The model is composed of sets, functions and relations. As the machine operates, the viewer sees both the mathematical and the physical operation. In other words, both abstract and realistic representation occurs making the intangible tangible. During the research I explored how to distil pictures for dual coding as well as arranging the pictures and words from studying and applying graphic design principles.

4.2.3 Graphic design

To answer the research questions, TOAOCP used graphic design theory including distillation, the gestalt principles,comic book theory and information design in the construction of the milestones (see Appendix A). Graphic design is the arrangement of different visual elements in order to communicate meaning. The graphic design section firstly defines graphic design and then proposes reasons why there may be few pictures within the texts that educate computer programmers. A brief examination of the way books are written and the tools that write them follows to explain the paucity of pictures in learning programming. The dominance of typography within design also influenced the way graphic design communicated programming in some instances. Design authorship and agency are also discussed within this section and also how the two themes can influence the effectiveness of an artefact.

Definition of graphic design and historical impacts upon programming documentation
According to Assistant Professor Juliet Cezzar at New York's, Parson's School of Design, Graphic design is defined as " ... the art and practice of planning and projecting ideas and experiences with visual and textual content" (Cezzar, 2017). The history of mark making is ancient with specific impacts that have occurred through technology. I now discuss typography as it has been a dominant influence within graphic design to the extent that pictocentric artefacts are not the norm. Master typographer and a member of the Bauhaus, Jan Tschichold set forth rules for the standard practice of modern type in the book *Die Neue Typographie*. Within his book measurements were stipulated that included sizes of paper and guidelines for designers to establish a hierarchy of type to base their work on. The measured design of one of Tschichold's book covers can be seen in Figure 4.24. Within the book cover the sans-serif typeface takes a dominant position while the non-textual information is placed within what seems to be the least important position on the cover. While it is not the objective of my work to reproduce the history of graphic design, I note influences that have had a dominant effect upon the format of information delivery because they expose the gap in the literature that TOAOCP seeks to address.

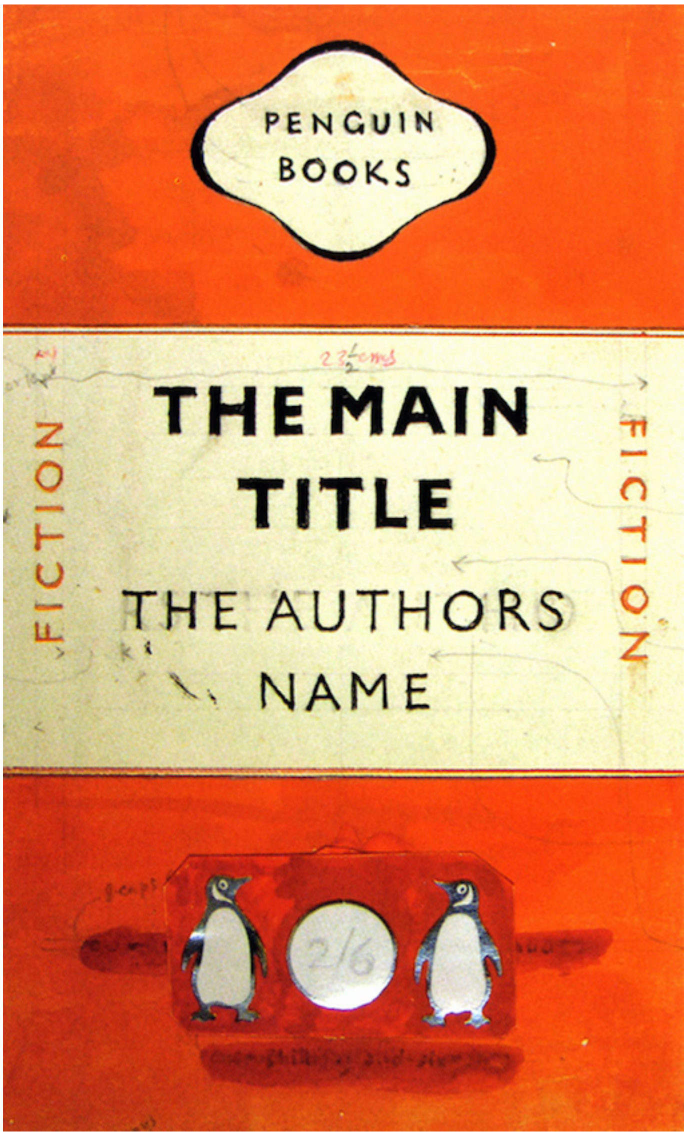

FIGURE 4.24: Book cover design, Tschihold, (1920s)

The effective communication of technical information through pictures is not widely documented within academia. Two influential theorists who discuss this type of delivery are Edward Tufte and Nigel Holmes. Tufte is a statistician who applies a formulaic approach to visualising information. Tufte prioritises different stylistic elements in contrast to Holmes, who is more concerned with the holistic communicative ability of the work. With holistic design, the novelty of the image is given importance along with successful communication. Holmes balances this aesthetic quality with accessibility. The balance of what a picture means, or its rhetoric, and the look of the picture is a matter of academic debate.

Graphic design began as an arts and crafts movement (Samara, 2017, p. 12). Professor David Sless holds a perspective that graphic design still works in reflecting industrialisation and concerns the physical form in contrast to that which we cannot see. Knowledge transfer through information would fall into this category, that is, what we cannot see.

Sless also contends that information design is closely related to graphic design, which is a craft rather than a profession. By craft, he is referring to the act of producing and copying physical objects over designing for things that cannot be seen such as information. Saul Wurman interprets the lack of rhetorical emphasis as 'shallowness' within the education paradigm of the discipline of graphic design, stating that:

> . . . most of the curriculum in design schools is concerned with teaching students how to make things look good. This is later reinforced by the profession, which bestows awards primarily for appearance rather than for understandability of accuracy. (Wurman, 2000, para:5)

Within TOAOCP a knowledge test was used to measure the accuracy of the pictures to ensure they were effective.

This section now continues by examining some of the typocentric style diagrams used within computer programming to communicate the discipline. I also examine why these diagrams may not be effective for novices.

Historical examples of graphic design, illustration and images used to communicate programming

There exists evidence of graphic design within the discipline of computer programming. This section within the literature review examines the use of graphic design within complex learning. Jef Raskin, the original designer of the Macintosh computer and William Horton, e-learning expert and author of *Illustrating Computer Documentation*, both believed that injection of visual communication would benefit the software discipline. The discussion begins with Raskin's case. During the seventies, Raskin wanted a poster designed on the coding statements containing priori units or literals, in the Pascal coding language. This artefact was to be above every programmer's desk on the wall for quick reference. However, before Raskin had a chance to put the programming concepts onto paper, a graphic designer who was more of a typographer was contracted to complete the brief. This designer focused solely on the typography (see Figure 4.25). During the creative practice in Research Phase One, to understand Raskin's perspective, I applied graphic design principles to the Smalltalk syntax (see Figure 4.26). I did not copy the poster but instead applied a pictocentric approach to the creation of it. This approach resulted in an infographic style structure as opposed to the typocentric list in Figure 4.25 that does not recognise any of the transverse relationships between the linguistic elements. Raskin's memory of the Pascal poster incident was as follows:

> The artist had no idea of the functional aspect of the colors, and assigned colors at pleasure, losing much of the utility of the chart . . . the colors no longer conveyed the information intended. They didn't make sense. (Raskin, 2004)

These comments are only a few of many regarding the bias of information and its presentation. Raskin may have believed that the designer responsible for the Pascal poster had a bias toward typography given the relationships between the different programming elements represented on the poster. This bias is discussed in detail in Section 4.2 from the perspective of Nigel Holmes (Kan, 2015). Persuasion, bias and rhetoric and their application to learning are themes that reoccur throughout TOAOCP.

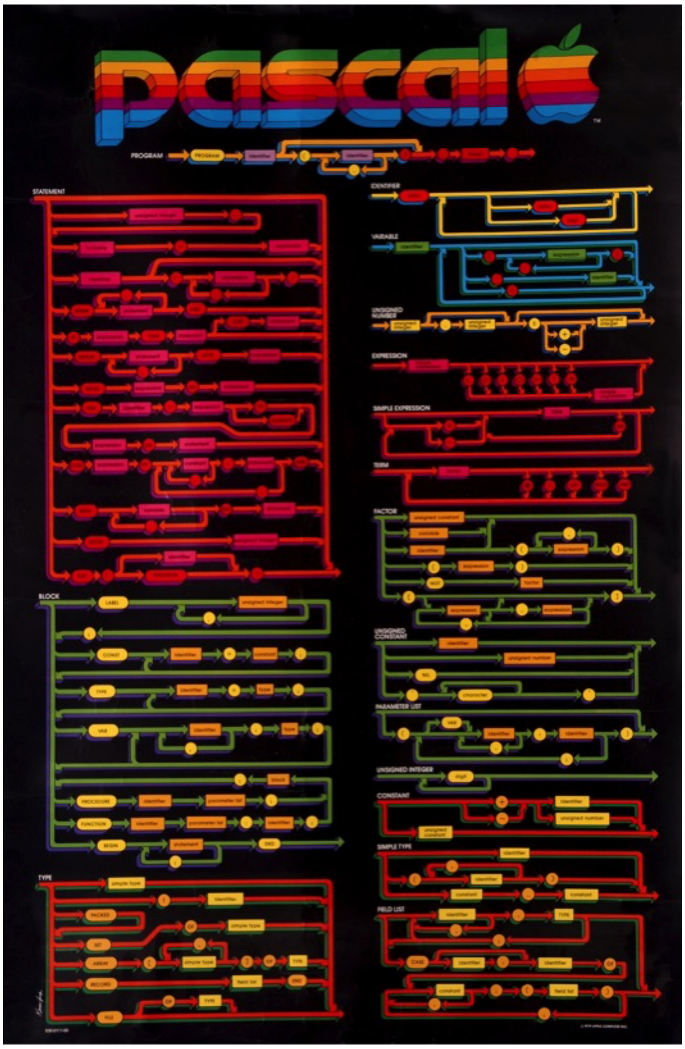

FIGURE 4.25: Pascal poster

Jef Raskin is not alone in wishing to apply design principles to computer science documentation. Another author who has stressed the importance of design and drawing in programming is William Horton. Horton's book *Illustrating computer documentation, The Art of Presenting Information Graphically on Paper and Online*, details different forms appropriate for creating programming manuals (Horton, 1991). The guidelines within Horton's book concern graphic design, inclusion of pictures and images as well as layout and rhetoric. The book's rules on complexity could also be applied to designing pictorial languages, to labelling with icons and drawing meaning from the screen. He is quick to acknowledge that the book may be a blueprint for technical documentation in general. However, many of Horton's suggestions remain un-adopted. Horton devotes chapter sections to reaching non-readers and also suggests design techniques to persuade reluctant readers. Horton agrees with Rudolf Arnheim's ideal of "eyesight being insight" and cites other well-noted designers such as Nigel Holmes within his book (Arnheim, 1974; Horton, 1991). Horton's book provides a rare account of how to combine visual and technical communication holistically.

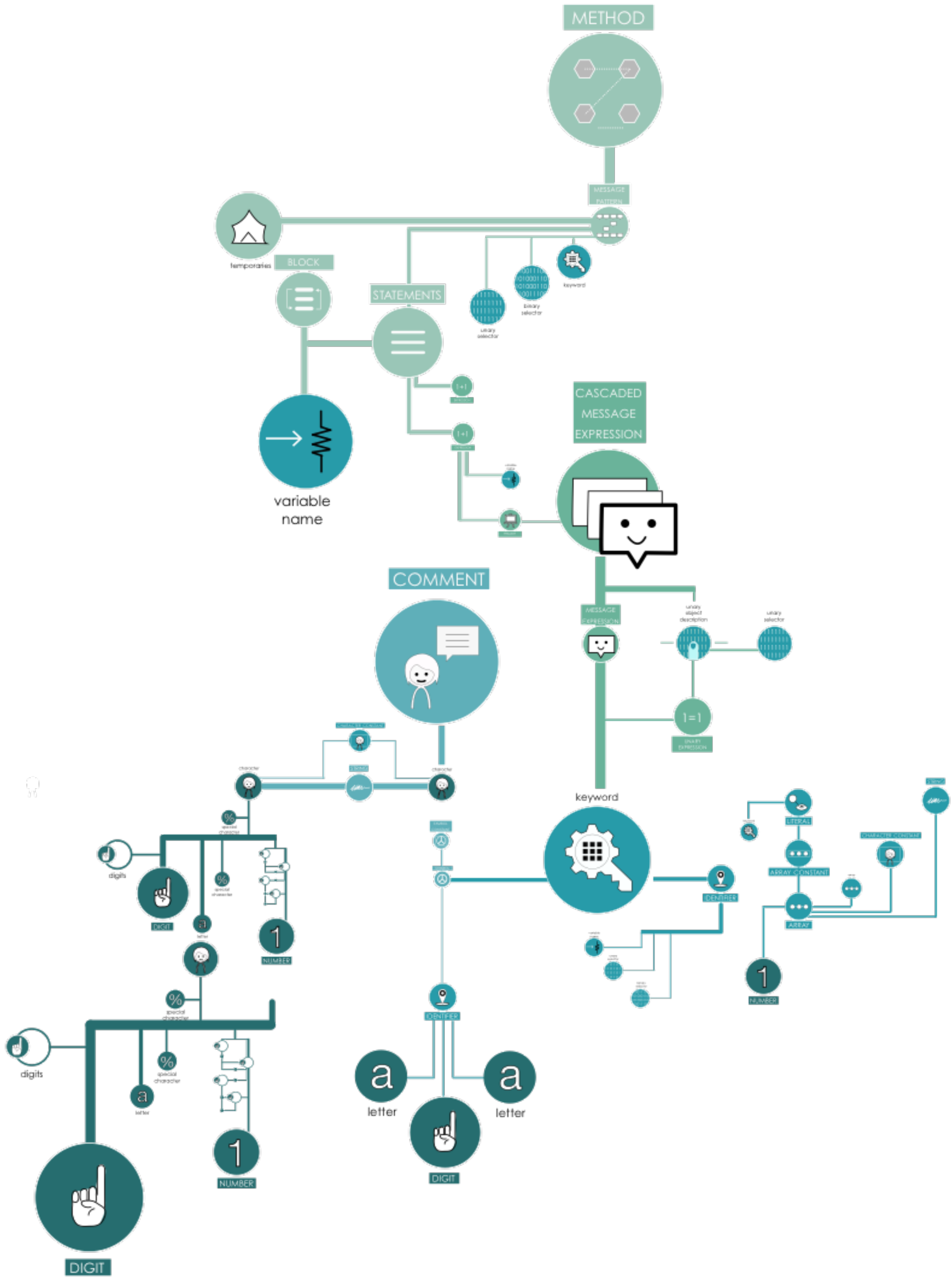

FIGURE 4.26: Smalltalk poster

Design authorship and level of agency of pictures

Authorship refers to who has authored or created an artefact. The term authorship is interpreted widely, however, design lecturer Cristina de Almeida states that authorship carries "...increased responsibility of the designer over the content of the designed message..." (De Almeida, 2009, p. 188). TOAOCP deals with the creation of learning artefacts. Within the learning artefact there are levels of agency within the different elements. For example, there is text and typography and there are pictures and visual design within an artefact. The level of agency within TOAOCP refers to choice of the amount of each of these elements in relation to each other. A graphic designer that has authorship over a learning artefact, may ensure that the artefact is given a high agency of pictures within it. A writer or content creator without an understanding of graphic design, may give a higher level of agency to the linguistic content or text of the artefact. Scardamalia and Bereiter (1991) first introduced the idea of a level of agency to the education discipline. At this time the education environments were being challenged to enable each student to guide their own knowledge acquisition. TOAOCP focused on giving the graphic designer a high level of agency in the construction of the learning materials.

The volume or amount of each element within the artefact such as text, in comparison to picture was an issue raised by participants in the focus group sessions. A further discussion of these volumes within the focus group results, occurs in Chapter 6, Section 6.3.

Information design will now be used to explain how picture arrangement can facilitate learning complexity. Information design is also not considered as a formal method of communication within education.

4.2.4 Information design – the systems of seeing

Information design is predominantly about the arrangement of pictures that are not highly realistic and favours iconic abstraction (McCloud, 1993b). The intentional reduction is a choice that a designer makes in order for the images to be learning appropriate. Within learning, realistic reduction was explored by Wileman (1993) and before that by Dwyer (1992). Much information design takes the form of diagrams, pictograms and icons. Arrows are also made use of to reveal hidden relationships between the distilled visual images. The order, placement, arrangement as well as pattern choices of the visual elements can all be taken into account by a designer when creating a work. Information design can be powerful when used in learning as the information can be reduced, distilled and the visual elements can be rearranged at will. Both features mentioned in the last sentence cannot occur within a unaltered photograph such as a screenshot.

Information design is seen as a sub-discipline of graphic design and has its roots in making research accessible for designers (Waller, 1996). Designing what cannot be seen (or "information") is not a routine practice within education and this is another gap in the literature that TOAOCP addresses.

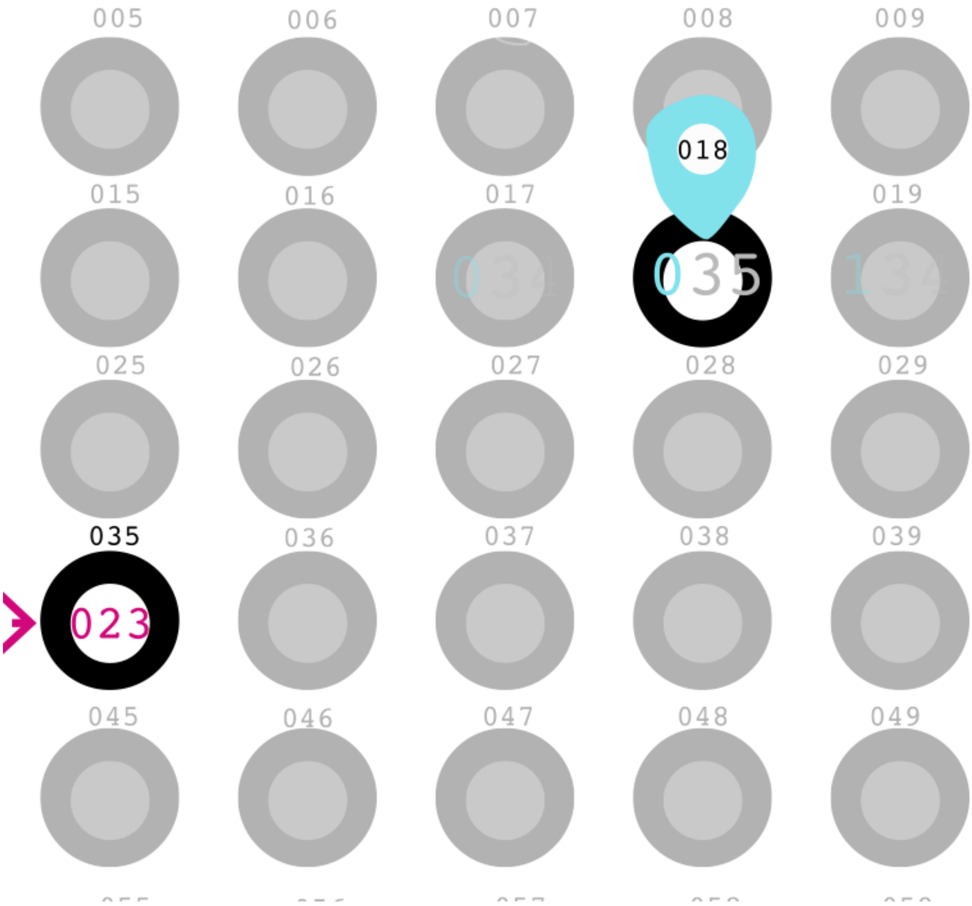

FIGURE 4.27: Memory cells, Tarr (2018)

The visual nature of information design allows a designer to illustrate elements within their communication precisely. Designers therefor include and exclude any design element required within a diagram. Information is diagrammatically made in contrast to imitating that occurs with more the more photo-realistic design forms. Systems of drawing employing gestalt principles can make the complex simple (see Section 4.3.5). Within TOAOCP the law of similarity was used to represent the computer memory (see Figure 4.27). Information designers understand how to manipulate visual systems for clear communication. In this way, the visual communication becomes contextualised. The example below was chosen to be included in this thesis because it represents technically complex information visually (see Figure 4.28). Noted information designer Peter Grundy has juxtaposed items within the cloud above items on the earth that actually operate the cloud. Relationships between the cloud and the software that stores the data in the cloud are represented through lines with varying widths. The data center and branch office all appear roughly the same size on the diagram although in the real world they may not be.

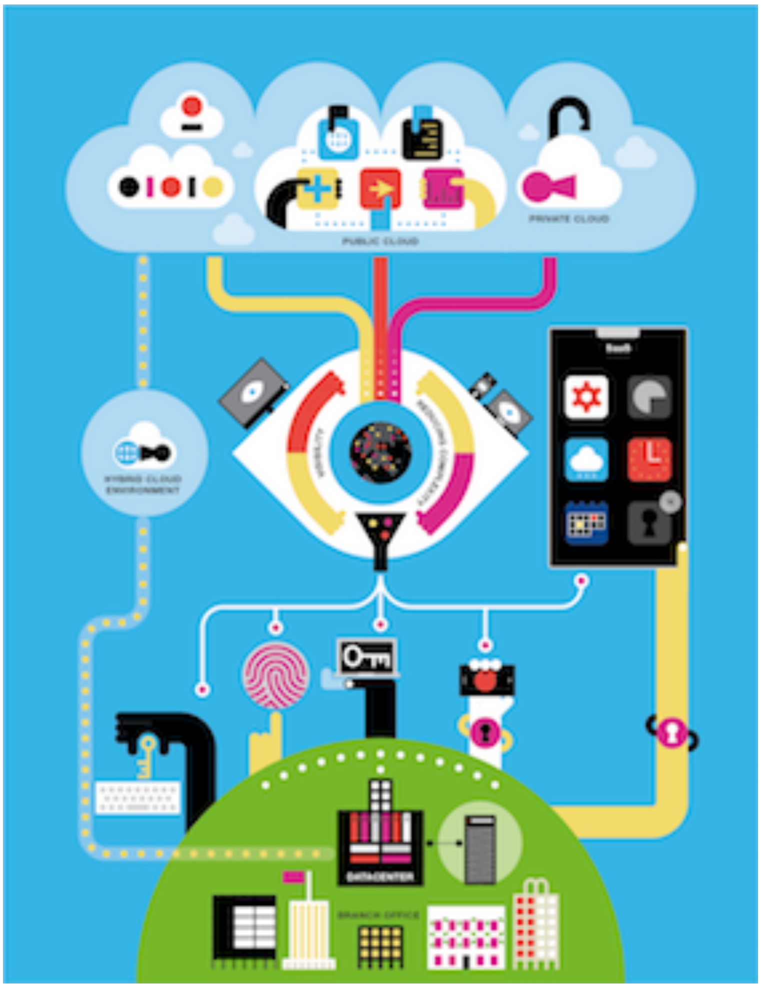

FIGURE 4.28: Citrix Netscaler, P. Grundy (2018), permission to use figure

Computer programmers do not routinely use information design of any of the principles and features mentioned in this section to communicate their craft. For this reason, information design and programming is a gap identified by the literature review of this thesis. TOAOCP used information design in the construction of a syntax diagram where transverse relationships were visible between the individual parts of the syntax Figure 4.26. The gestalt principles are covered in detail in Section 4.3.5 and were mentioned here because they were also used in the information design exercise to represent the programming language.

An infographic is a visual representation of information intended for quick and clear communication (Smiciklas, 2012). When correctly designed, infographics improve cognition as they take advantage of and enhance a learner's perceptual ability to see patterns and trends (Heer et al., 2010; Sears & Jacko, 2009). Infographic scholars promote the idea of giving priority to information and the motivating effect this has upon the beholder looking at the information longer (Grimwade, 2003).

Diagrams

Computer science diagrams used to explain programming are discussed further in Section 4.4.4. Diagrams are discussed now because of the differences in the approaches to creating diagrams by professionals within different disciplines. Diagrams within computer science documentation contain shapes and text and are often devoid of any objects resembling the real world. TOAOCP used diagrams containing pictures of the objects that were involved with the programming exercises as well as pictograms to represent the code and dotted lines to represent relationships between them. The approach used to visually represent programming in TOAOCP is different to visual approaches used in computer science (see Section 4.4.2). The approach is unique because I apply graphic design techniques to programming documentation.

Aside from the previous paragraph that addresses the aim and gap in the literature, I will begin with a discussion about the work of Professor Emerita of Psychology at Stanford, Barbara Tversky who is an expert on diagrammatic cognition. Tversky has published seminal works on the cognition and the design of thought within the brain. Her research focuses on communication that is facilitated by a fundamental unit called known as an element. Elements can be depictive or non-depictive. Depictive elements are recognisable and often represent an object in the real world. She states that external representations, that in this case are pictures, use space and arrays of elements to communicate ideas (Tversky, 2015). TOAOCP used an array of elements to describe an algorithmic process called a bubble sorting procedure (see Figure 4.29 in milestone six).

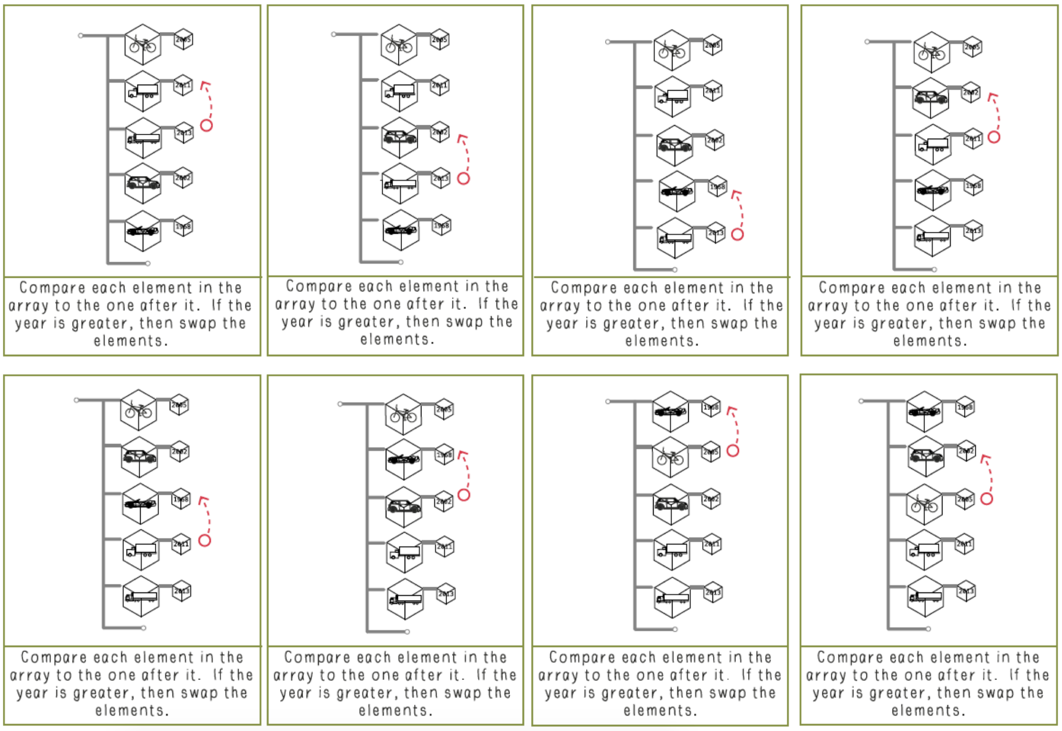

FIGURE 4.29: Bubble sort procedure - Milestone six

The article, *The Cognitive Design of Tools of Thought* contains two types of diagrams -

orderly and *messy* (Tversky, 2015). Orderly diagrams such as maps, graphs and visual explanations communicate clearly and assist in tasks. These diagrams omit any noise or unnecessary information and achieve the aim of communication or quick understanding. The second type of diagram, messy, is more process oriented and less centred around real objects. Tversky notes that the diagrammatic representation of thought is not straightforward or easy, and therefore takes a multitude of forms (see Table 4.6). The preceding sections have reviewed these different forms of diagrams and also gave some examples of where the diagrams have been used in TOAOCP.

Maps represent landmarks and spatially reflect the real world through markings on a page. Information on maps uses shapes and lines to represent paths geographically. In TOAOCP maps were used more than once to explain the layout or the topology of a system. Within programming documentation, topology in reference to where to program features are located are not addressed within the literature and pictures of the features that are being referenced are not used. The pictocentric (picture first) gap in computer programming is what TOAOCP seeks to explore.

The milestones listed (in Appendix A) are ideas and examples of visual communication that communicate programming concepts. The map-like diagram in Figure 4.30 is a spatial representation of the last milestone drawn for a lesson in the Swift programming lanugage that represents components of a car (see Appendix A). These components are also programmable features the car contains. Although not strictly fitting Tversky's map description, the modified style of map or diagram is useful to see the different components of the whole program. The car has ten components and features that are coded (see Table 4.3).

TABLE 4.3: Car object components and features

Component	**Icon description**	**Code listings**
A horn	Yellow solid horn	Two icons labelled car.h and car.m
A name	"Mustang" word	
Wheel number	Four wheels	
Gears	Gear shift pattern	
A date of manufacture	"1980"	
A power source	Blue icon with light bulb	
Ability to drive forward	Line pointing right	
Ability to drive backwards	Line pointing left	
Ability to stop	Red solid hexagon	
Ability to turn	Red circle with arrow	

An icon was created for each part and feature of the car and then the programming listings were attached to the icon. This was done so that an adolescent can see a clear correspondence to the programmable object, its component parts and the code. Lines within TOAOCP were chosen to represent either relationships or transformation of information. Information flow is not represented on this diagram as the lines represent relationships. Table 4.3 names the object's parts, as well as the features and code listing icons for the car in Figure 4.30. The red lines on the diagram represent things that can be seen, while the green lines lead to computation or things that cannot be seen.

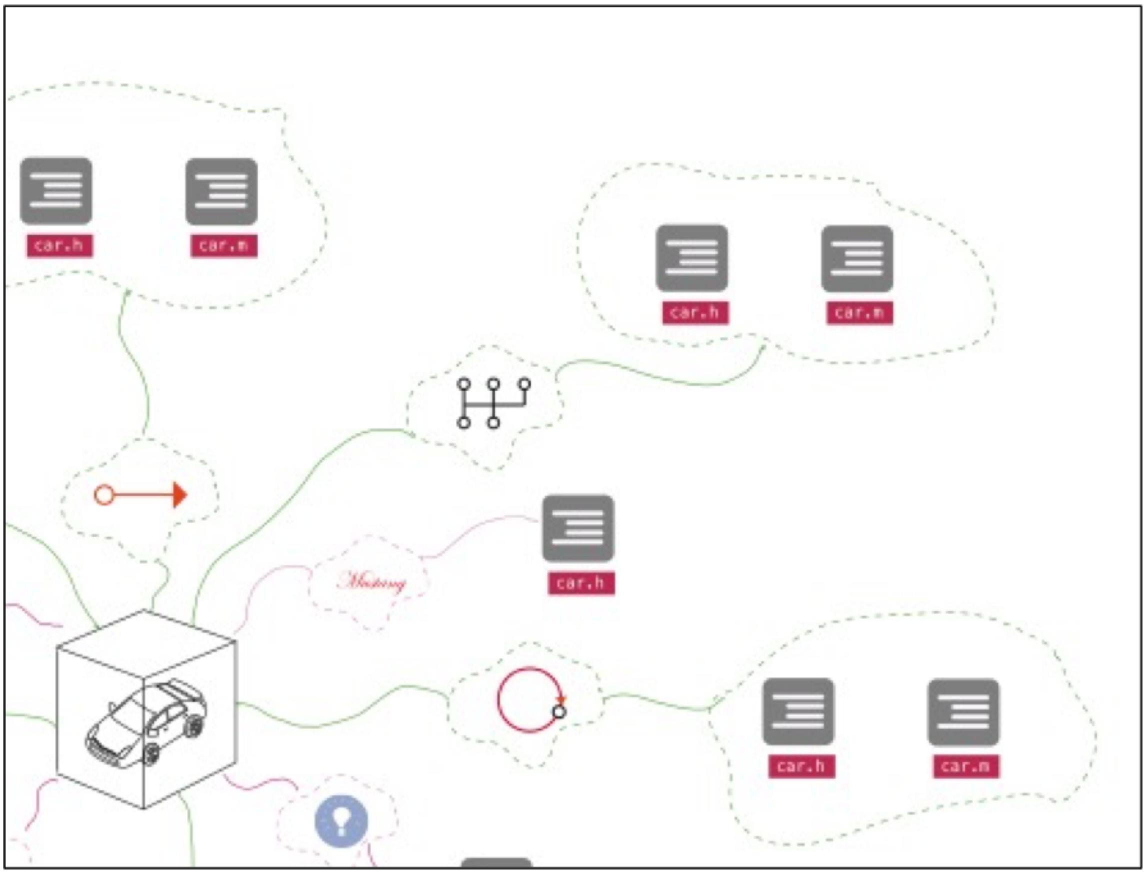

FIGURE 4.30: Close up of code listing icons

The diagram could be further enhanced by using the Gestalt principle of grouping by proximity where all the 'abilities' listed with the green lines were grouped together, and then all the parts of the car indicated by the red lines were consolidated together. Grouping of scenes of actions and class of things are either partonomic and taxonomic (Miller & Johnson-Laird, 1976); where a partonomy is a hierarchical classification of parts, and a taxonomy is a hierarchical arrangement of kinds or sets of things that share appearance and function. By using this visual categorisation, the schematic processes within the brain are assisted and cognitive load is minimised.

Diagrammatic arrays were a relevant type of diagram to use in TOAOCP and were used in the first milestone. These arrays are the bundling of interrelated actions into meaningful events so that an experience can be organised (Casati & Varzi, 1996; Tversky, 2001).

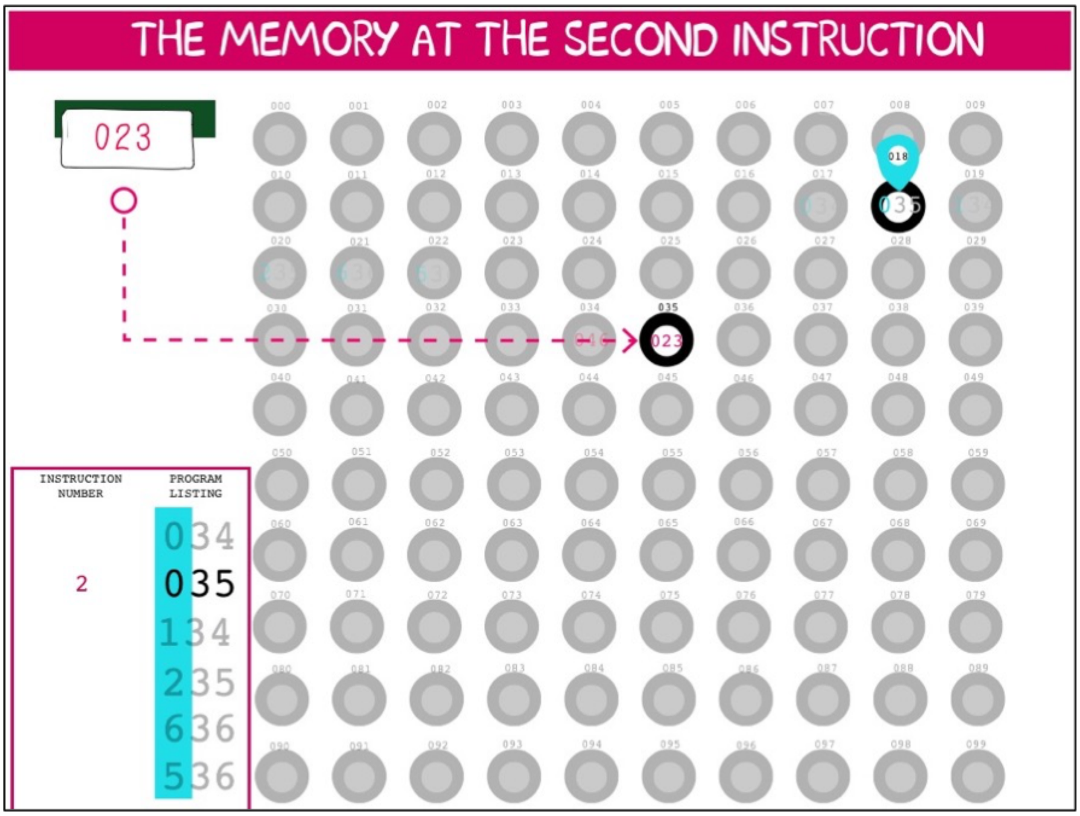

FIGURE 4.31: Memory cell array

Figure 4.31 is an example of one of eight pages used in the milestone one. The page used an array of a fundamental unit of storage or memory to indicate the location of execution in the computer's architecture. These pages exploited the use of an array to show the steps in program execution.

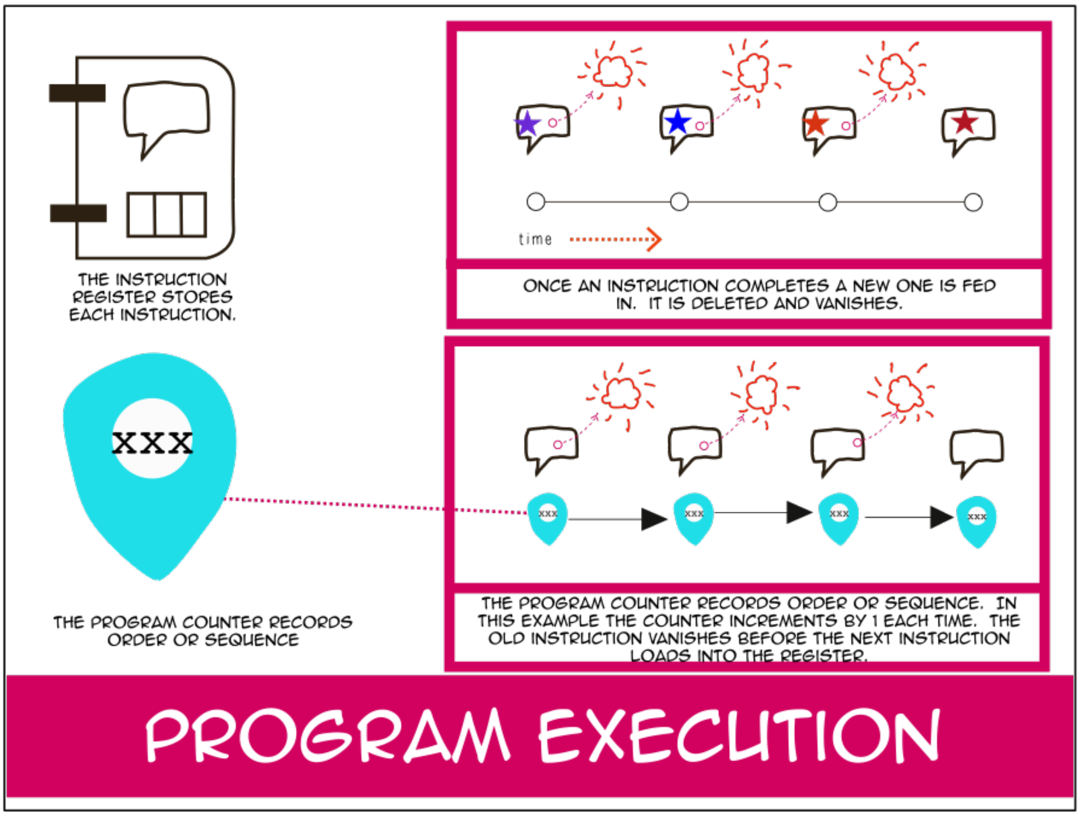

FIGURE 4.32: Data flow in the 1950s milestone

Arrows are classed as a way to diagram ideas. Within TOAOCP arrows were used mostly to represent information flow (see Figure 4.33). Pictures of data flow re-occurred within the lessons but were modified slightly to suit each of the milestones (in Appendix A) according to the colour and style. Within milestone six, program sequence is represented by the dotted line that the moth flies through (see Figure 4.34). The theme of data flow representing a dotted line was also revisited within other milestones (see Figure 4.32) and Figure 4.34). The arrows are used to represent time ordered sequence see Table 4.6.

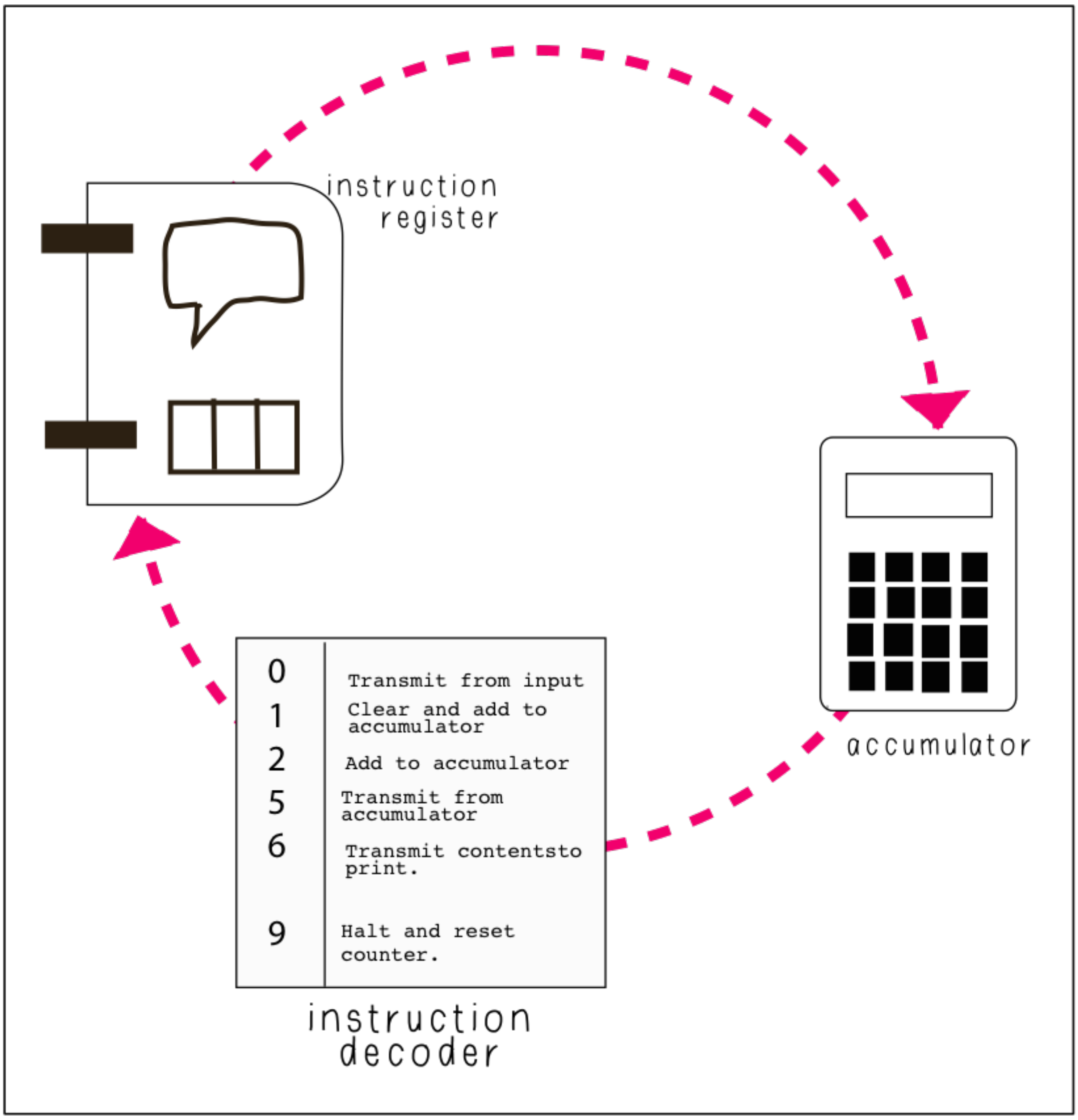

FIGURE 4.33: Arrows representing information flow

Tversky states that arrows are simple yet powerful geometric forms and that diagrams containing arrows are interpreted by the viewer as "... conveying behaviour in time" (Tversky, 2014, p .110). This behaviour is exactly what programming is. Arrows also signify causal relationships (Heiser & Tversky, 2006). In experiments using diagrams and causal action, where one event causes another, people readily interpret arrows as indicating the sequence of actions from start to finish (Heiser & Tversky, 2006). According to Heiser and Tversky (2006)people readily interpret and produce arrows in diagrams to suggest functional properties of complex systems.

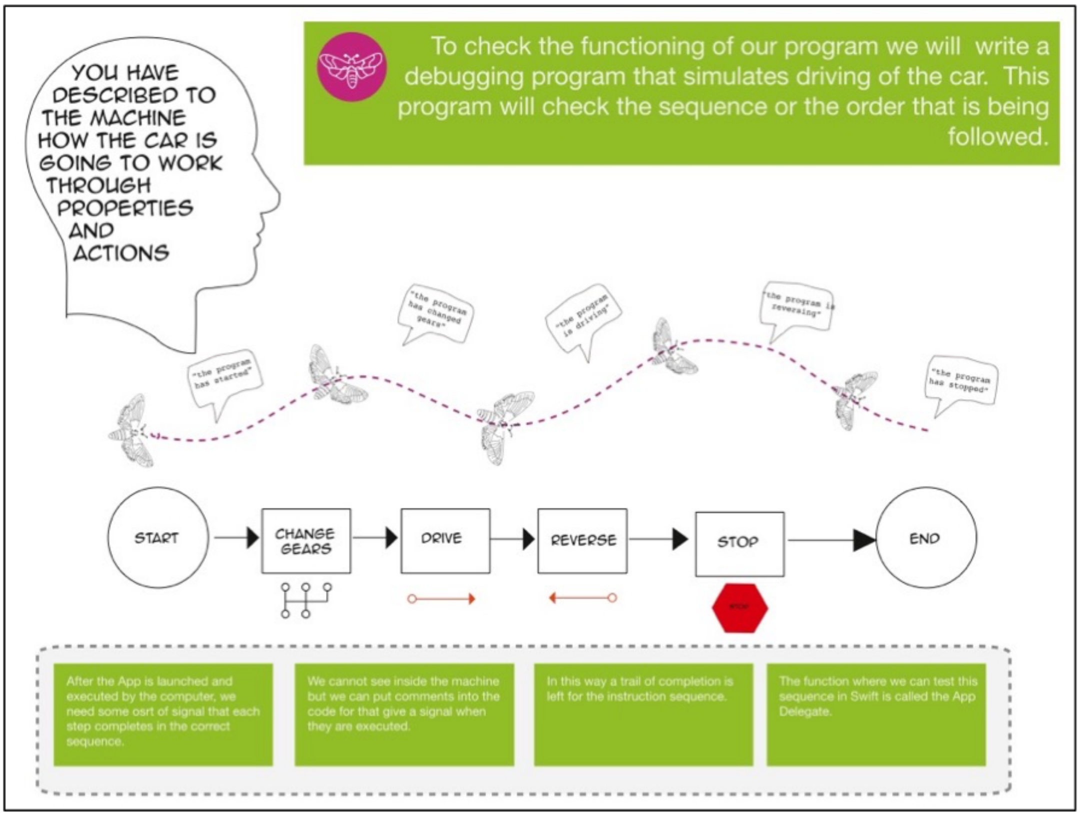

FIGURE 4.34: Data flow in the 2000 milestone

Sketches that are classified as messy diagrams, emphasize information that is productive for inference and omit information that is distracting (Tversky, 2014). Designers use drawing to see patterns and understand concepts (Suwa & Tversky, 1996; Suwa & Tversky., 2001, 2003). Sketches of the lessons were used throughout TOAOCP before any digital drawings were completed. Computer programming lessons are not routinely designed, drawn or sketched on paper before the final lessons are shown to students. According to Roels, Meştereagă, and Signer (2015) the majority of programming courses are at least partially taught via lectures accompanied by slide decks displaying syntax. Mayer (1981) states this type of teaching goes against research that encourages deeper learning through visuals. Furthermore, according to programming educators Roels et al. (2015):

> In the context of presentation tools, there exists little to no academic work trying to improve upon the issues associated with the presentation and visualisation of source code. (p. 2)

My research was positioned to contribute to the lack of academic work concerning the presentation of programming. TOAOCP's pictocentric approach to the milestones (see Appendix A) is a unique perspective upon lesson creation for computer programming through diagrams. The sketch and pictures used to represent information flow can be seen Figure 4.35. The diagrammatic types used in TOAOCP are indicated in the summary Table 4.6.

This brings to a close the first section of the literature review that concerns how through a pictocentric approach to learning, complexity can become clearer. Within TOAOCP this complexity was programming.

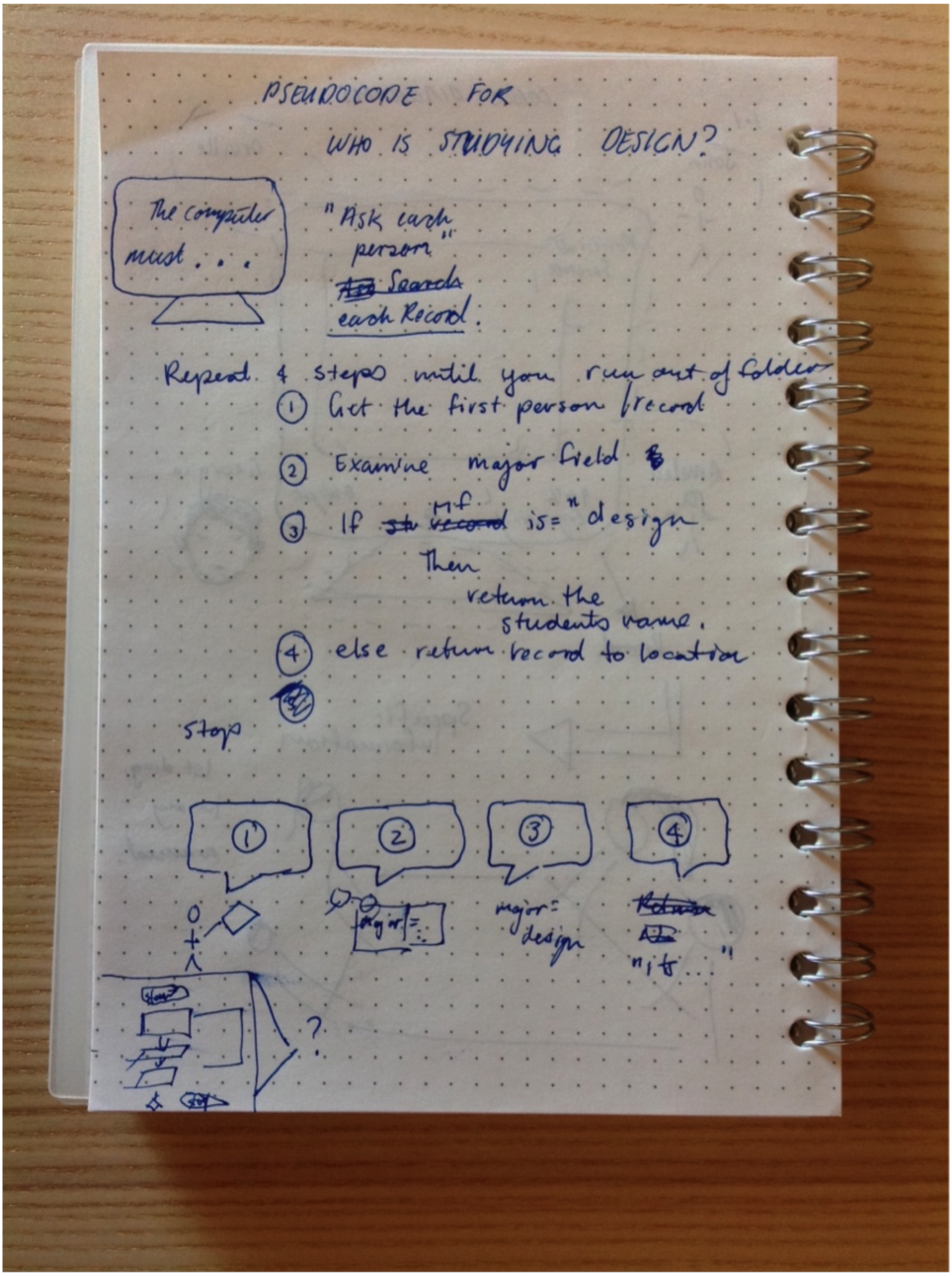

FIGURE 4.35: Sketch of information flow used throughout milestones

4.2.5 Expanding visual literacy and including pictures - drawing visual explanations

The acquisition of visual literacy by a learner is a possible solution to the communication issues associated with computer programming (see Section 4.1.2). Ausburn and Ausburn (1978) give the following definition of visual literacy:

> Visual literacy can be defined as a group of skills which enable an individual to understand and use visuals for intentionally communicating with others.

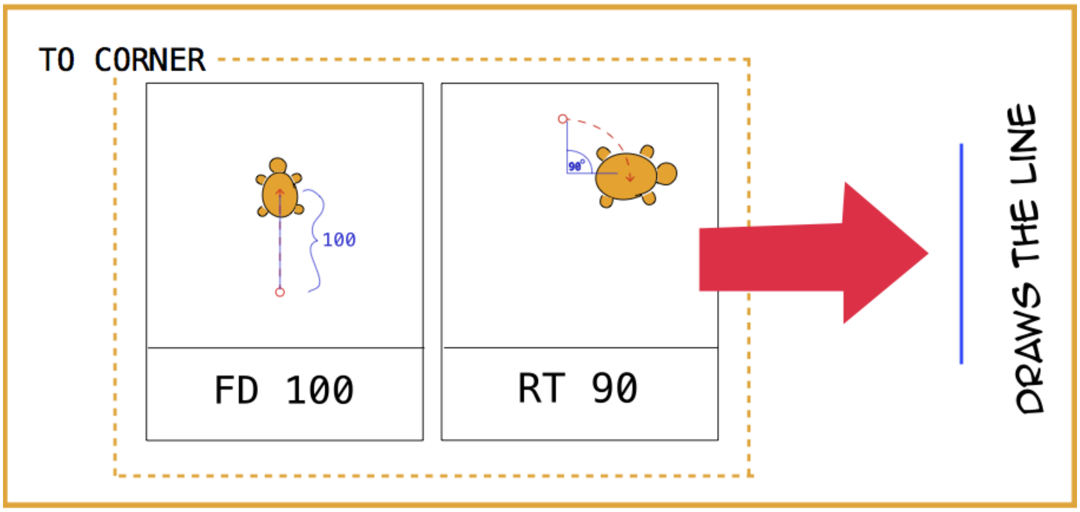

FIGURE 4.36: Breakdown of drawing a line - milestone two

Within TOAOCP both picture and code were displayed together (see Figure 4.36). Prior knowledge is defined as:

> Prior Knowledge relates to the pre-existing information and prior understandings held by students before instruction begins. Such prior knowledge consists of accurate perceptions along with misconceptions (see also) and alternative conceptions. Prior knowledge can either support or interfere with future understanding. (McComas, 2013, p. 74)

Images assist in the creation of new knowledge such as computer programming as well as building upon prior knowledge (Pratschke, 2011). Visual forms of information in education facilitate the integration of new knowledge with prior knowledge, particularly in the area of unseen science phenomena (Ainsworth & VanLabeke, 2004; Buckley, 2000; Krajcik & Blumenfeld, 2006; McNeill et al., 2006; Roth et al., 1999). Figure 4.37 shows a desalination experiment, that is, the process of turning salt water into fresh water.

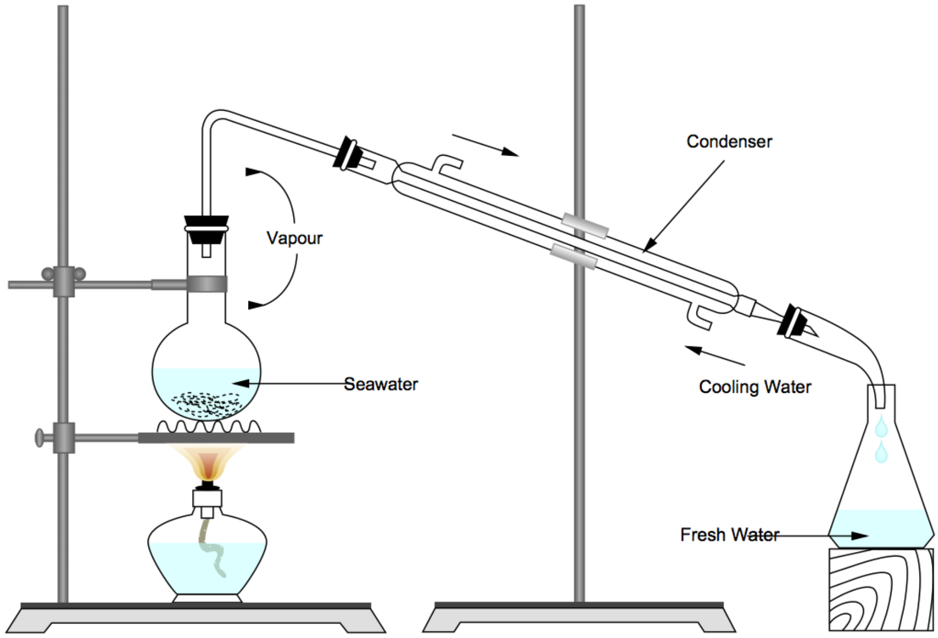

FIGURE 4.37: Desalination experiment

Studies into Bloom's taxonomy and learning theory acknowledge the role of visual literacy in the way the creator of the information arranges the information, for the cognition of concepts (Efland, 2002). The level of visual literacy that a student possesses as prior knowledge can affect the understanding of the combination of pictures and text. High visual literacy is a factor that has been assessed when studying visual rhetoric and visual information (Cook & Frey, 2017; Lemper, 2014; Steeves, 2015). Even though a particular graphic may be designed to be cognitively useful, it may turn out to be functionally useless unless the learner perceives the information in the way the information was intended. Cook (2006) states "These individual differences, especially prior knowledge, are critical in determining what impact that visual representations and their design will have on learners' cognitive structures and processes" (Cook, 2006, p. 1074).

According to Braune and Foshay (1983), learners use prior knowledge to select information from graphics. This idea ties in with Glaser's research on the differences between the cognitive structures of experts and novices. The construction of mental models (see Section 4.2.3) are assisted through the creation of external representations or pictures.

An appreciation of visual literacy by educators is necessary for this type of visual communication to have a high knowledge transfer. This section defined visual literacy according to intentional communication. When intentional communication is successful, intent to learn (see Section 4.5.1) is also positively impacted as an individual feels they understand the information presented. My research focused on distilled pictures and the affects this has upon learning complexity. Drawing is the way that I created the pictures. Visual literacy in Australian education requires an understanding of image construction by students. However picture creation is not defined in the context of drawing, and neither is visual perception (ACARA, 2018). Support for distilled pictures and learning through them is the gap TOAOCP seeks to address. Educating students in drawing is one way to address the creation of pictures for complex learning for students.

Drawing education
The time spent learning to draw pictures within design education has reduced within institutions dramatically in the last century. The absence of drawing instruction within the school system has not gone unnoticed within the design community at large. Concerns such as "...children are not taught drawing..." are echoed from designers trained by Bahaus alumni (Bell, 2016). Roberta Bell is a designer educated by Phyllis Shillito in the 1930s at the East Sydney Technical College; now the National Art School (NAS). As Shillito trained at the Bauhaus, she took it as her duty to bring the ideas to Australia. Bell insists that she had to study 'three years of drawing' before she was allowed into the design program at the East Sydney Technical College (ESTC). Her forementioned comment about the role of drawing and the teaching and learning of drawing is one of many about the absence or lack of traditional tuition in this area (Taylor, 2014). Drawing within design is the process of creating intentional pictures that communicate. Since the time spent learning drawing has been dramatically reduced in the last century, the perceptual skills acquired through this process by students has been lost.

Art and design are far from synonymous however communication through non-linguistic form is common to both areas. The difference is the goal of the creator. Often the artist will seek self-expression in contrast to the designer who seeks clear communication. It is this drawn ability of making things clear through the creation of a form that supports meaning-making. Today a child is lucky to receive one hour of art tuition a week within government education. The marginalisation of drawing, one of the main tools that supports creativity and innovation that are so highly prized by current government policy, has been described by Professor Robyn Ewing from the University of Sydney as:

> ...a lack of understanding of what the individual arts disciplines are about and that "creativity, problem-solving and developing out imagination" are as important as literacy and numeracy "if we expect kids to solve the problems of the 21st century (Ricci, 2015).

This thesis is an enquiry into how drawings may be incorporate into graphic design for the learning of complexity. Through combining a craft such as drawing with pencil and paper with modern technologies, it is possible to enhance a learning environment. In TOAOCP, through the crafting of pictures, a new form of meaningful information and learning was produced (see Section 6.2.3).

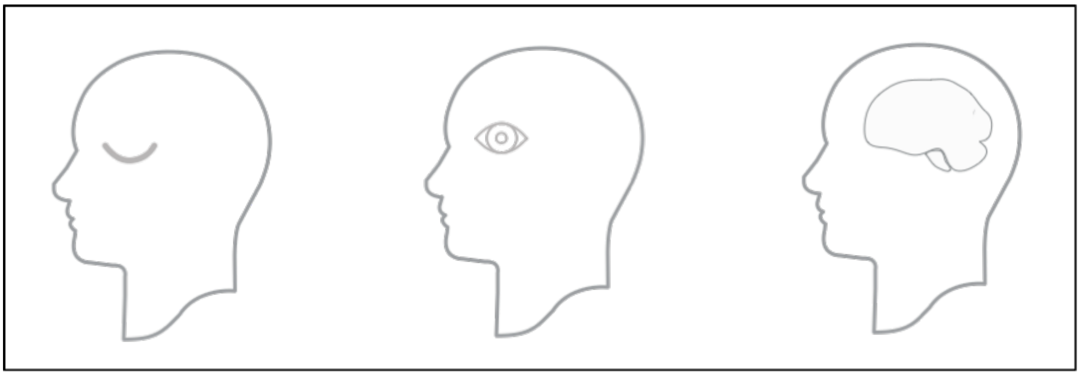

FIGURE 4.38: Three types of vision

Communicating what cannot be seen

McCloud is a noted comic book creator and expert on picture types used within them. He also understands the importance of visual thinking and picture creation to cognition, invention and innovation. In his TED presentation, *The Visual Magic of Comics*, he explains his preference for those topics that are measurable and can be seen as opposed to subjects based upon faith and things that cannot be seen (McCloud, 2005). Objects seen in the physical world are easy to draw as they can be seen. These objects are are also measurable as they exist in the physical world. He continues on to explain there is a middle ground that inventors such as Charles Babbage occupy. Here the inventor's imagination or visualisations of nothing that is yet physically seen eclipses the known to produce something new. Not all ideas are easily communicated. McCloud classifies vision as having three subtypes. These types of vision are listed in Table 4.4 and their associated pictograms can be seen in Figure 4.38.

TABLE 4.4: Three types of vision, Scott McCloud's three types of vision (2005)

Vision	**Description**
1	The unseen and unknown
2	The seen, which has been proven and ascertained
3	The imagined but as yet unseen or unproven

The memex was an early hypothetical device that an individual could store all their books, records and mail in. The device (see Figure 4.39) was mechanised and contained an index that could be used to access details at high speed. McCloud cites Charles Babbage and the inventor of the memex, Vannevar Bush as among those that possess the third type of vision. McCloud states that Vannevar Bush "... understood the shape of the future" (McCloud, 2005: 3.40). This reference to that which can be mentally seen by someone, but is yet to be proven, is made many times in this particular TED talk. McCloud acknowledges this third type of vision as being a way of looking at the world. He acknowledges its presence within the arts and other disciplines. At this stage of the research, I had begun to wonder what part drawing plays in visualisation and innovation. For example, I was curious to know how often computing concepts were drawn before they were created in comparison to prototypes, and what thought processes occurred during the drawing process. Accounts exist on both Turing and Von Neumann's childhoods that documented what they drew as children. Turing made quite detailed botanical drawings and is known as the father of AI, while Von Neumann often drew battleships and created the atom bomb through the monte-carlo subroutine. The monte-carlo subroutine generated random numbers making the atom bomb possible. Taking these examples into account the drawing process could be seen as contributing to cognition.

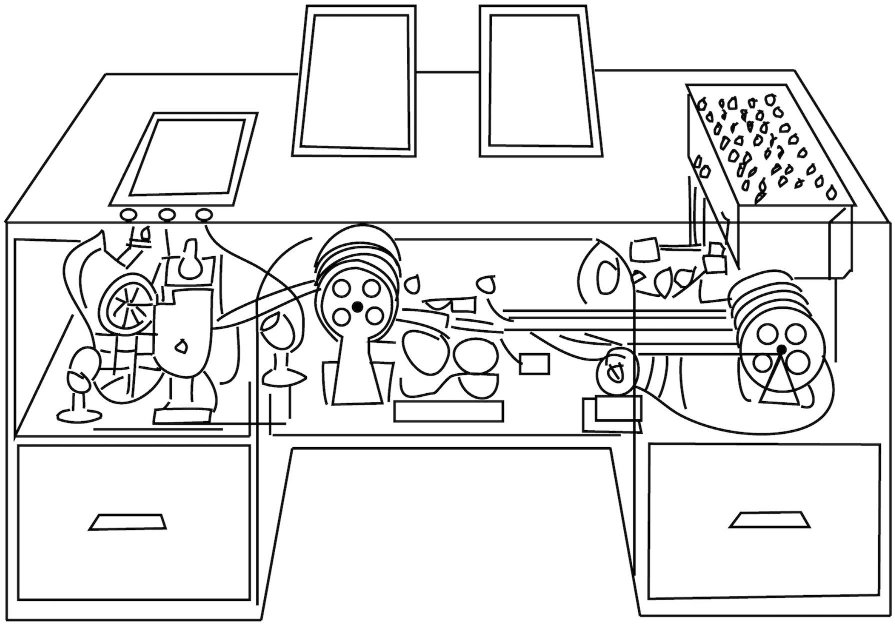

FIGURE 4.39: The memex

The sequence of picture presentation is a fundamental aspect to consider within the design of a comic. This sequence or order is important for specific cognitive reasons (McCloud, 2005). The layout of a comic forms a temporal map through which the brain can gain knowledge quickly. If this sounds like the spatial learning through schema and aligns with Piaget's research, then it may be that it is ideal for teaching subjects like computer programming that require sequence or steps where data transforms into information. Programming is traditionally taught by listing a series of steps and copying their coded explanations. As the research in TOAOCP comes from the premise of the brain learning through organisation, or schema, as well as representation, comics become a natural choice for the presentation of programming. Section 4.3.8 presents findings from experts on the reduction of cognitive load and information anxiety when using comics (Azman et al., 2016; Bitz, 2004; Tisseron, 1987). The structure or presentation of the panels is also examined to understand how panel arrangement assists learning schematically. The positive results concerning the participant cognition in TOAOCP from using pictures in a sequenced series to explain computer programming are in Chapter 6, Section 6.2.1.

McCloud makes a point of situating comics as an emotional device stating they embrace most of the senses. This is not dissimilar to Don Norman's idea of learning through emotion. When learning from comics, many different networks are engaged within the brain of a learner. This engagement is suggested in Universal Design for Learning (UDL) (see Section 4.3.7). This concept of emotion addresses the pathos characteristic of rhetoric within an artefact (see Chapter 8, Section 8.2.3). The delivery, in this case the comics delivery, can affect emotion.

McCloud further suggests that he approaches creating comics from a scientific or logical perspective. Again this is addressing a type of rhetoric, this time, logos or logic. McCloud's emphasis here is upon finding patterns, this is another reason that I considered comics as a medium to teach computer programming. Patterns are a component of computational thinking. I found that particular patterns began to emerge on the pages of the comics I created for the milestones from the 1960s onwards (see Appendix A). Some of these comic structures even resembled Unified Modeling Language (UML) 2.0 sequence diagrams that are a commonly used form for communicating computer programming (see Figure 4.40).

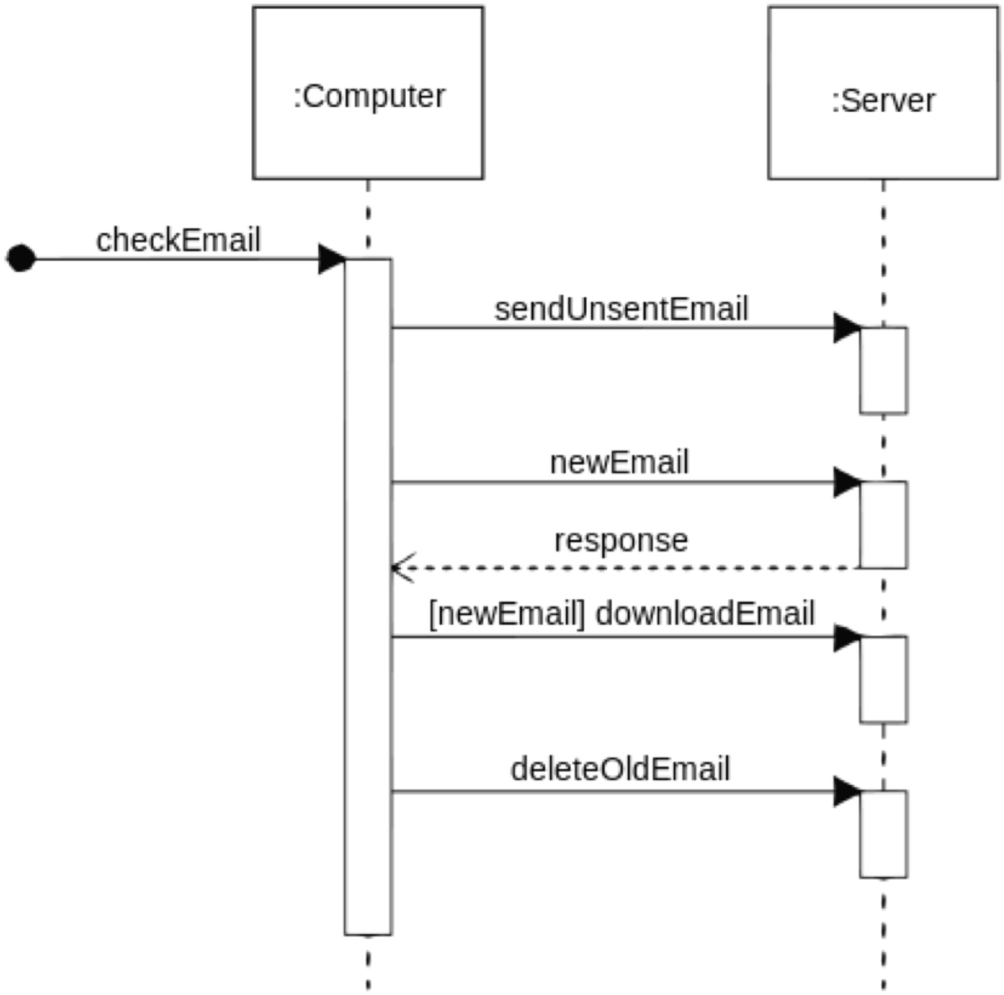

FIGURE 4.40: UML 2.0 sequence diagram

Within TOAOCP, different visual devices worked for different types of information. For example, arrows can indicate components that are part of a whole or they can indicate order of execution while comic panels suit sequence or programming commands that have a specific order (see Figure 4.59). There are key differences in designing for print and digital mediums, as there are constraints within digital mediums that do not apply to print. The experiments conducted in TOAOCP provide a strong argument for learning computer programming through pictures and printed documentation.

4.3 Psychology and interpretative faculties of vision that contribute to learning computer programming

Learning is the second major section of the literature review and deals with cognition and pictures as external representations for learning. External representation concerns objects outside of that individual's body that assist in cognition. According to research on how to communicate complex systems (Zhang & Norman, 1994) there was a communication issue concerning external representations and learning in that it was unclear exactly what form these representations should take. This was despite how the external representation should be perceived by a learner of the represented cognitive task. These communication issues still exists in programming (see Section 4.1.2).

Pictures are the external representations in TOAOCP created to fulfil the role of representing complexity. As explained previously (see Section 4.2), learning within TOAOCP is more specifically learning through pictures. Some scholars have labelled this as visio-spatial while others give a more generic label of 'visual learning'. Within TOAOCP I have called this visual approach to learning, pictocentric. As pictocentric learning occurs through the sense of vision working in conjunction with the brain, the focus of Section 4.3 explains what role the brain plays in this learning.

This section begins with an explanation of the design of elements and components that assist cognition. The section then continues with a discussion on schema as a concept that contributes to knowledge transfer (see Section 4.3.2), considers design devices (see Section 4.3.3, Section 4.3.4) and theories (see Section 4.3.5, Section 4.3.6) that can contribute to communication and lastly concludes with some barriers to learning that designers can have control over (see Section 4.3.8).

4.3.1 Designing learning for the brain

Humans have brains that are pre-adapted to imitate the actions of others. The ability to imitate another plays an essential role in learning, from copying art and maths to tool use. Cultural transmission, through imitation, enabled inventions in early cultures to spread quickly (Tennie et al., 2017). Oldowan stone tool use was culturally assimilated in palaeolithic culture because one human ancestor copied another. Neuroscientist Ramachandran states that our imitation ability is due to mirror neurons within the frontal area of the brain (Ramachandran, 2009). These neurons respond directly to the sight of something, a picture or a goal-directed action that occurs. Mirror neurons are the reason an individual reactively smiles in response to another's smile. The confirmation of the existence of mirror neurons would also serve as a reminder to design toward ecological biology first. Designers can ask themselves, what is the best way to communicate this information? A decision can be made if imitation needs to be the learning goal or whether there is a deeper underlying concept that is best conveyed through abstraction from visual realism or representation. It may be the case that mirror neurons only respond to the more realistic pictures. The response would explain some of the recent advancements in understanding gestural responses in human-computer interaction (HCI) and why animation works so well for this imitative type of learning.

The evidence that mirror neurons exist may also add further persuasion to Norman's three levels of design (Norman, 2004) as previously discussed in Section 4.3.1. Table 4.5 lists Norman's levels of design experience and how they apply to TOAOCP.

TABLE 4.5: Norman's design experience examples

	Visceral	**Behavioural**	**Reflective**
Purpose	Make rapid judgements	Performs something	Message and meaning of product
Determined	Biologically		Contemplated
Characteristic	Affective Automatic Perception Emotional Bottom-up	Function Achieves end goal Motivation	Cultural Evokes self image Top-down Cognition Attitudes
Example	Warning signs	Roller-coaster (Fear part) Tool use such as a knife to cut something Walking	Roller-coaster (contemplating safety) part)
TOAOCP Example	Narrative characters Pictograms	HCI directions in Milestone Six	Intention

TOAOCP is positioned to influence all three levels in Norman's concept of designing to elicit emotional responses. Research Questions One and Two attempt to answer the impacts upon the cognitive and motivational factors of learning. Cognition and motivation in TOAOCP influenced the behavioural levels proposed by Norman. Research Question Three considers the beliefs and values of the learner within the reflective level of Norman's theory. I created pictures, colour and line art within the lessons to produce a visceral response in the participants. The visceral level can capture attention and concerns the aesthetic impact of the artefact (Ernst & Horstmann, 2018).

When considering biology and these three levels of design, mirror neurons may work in tandem with the visceral level of the design rather than the behavioural. The behavioural level may invoke a different region of the brain. As discoveries about the brain and learning through pictures advance, the knowledge of what area of the brain we are designing for will guide and impact visual design. Schema is the focus of the next section (Section 4.3.2) a concept that works with vision and thought to facilitate organisation and structures of learning within the brain.

4.3.2 Schema

The schematic representation of picture and code within TOAOCP transferred knowledge to the participants. Organisation of different communication modes to facilitate the schematic process is schematic organisation, or schema (Gombrich, 2002; Gregory, 1977). The schema function marries what the eye sees with what the brain knows. When the eye sees something it recognises, then a stored 'norm' for that particular object or topic is invoked (Rhodes, 1996). Organisation in this way occurs through cognitive apparatus in the brain and operates as a memory device.

A component of investigation within this study is what a picture should look like when it represents an abstract process or idea. Most educators do not teach how to make pictures and TOAOCP attempted to quantify how a picture should be constructed through co-creative processes within the qualitative methods. Many scholars have noted the presumption of assumed knowledge by scholars of pictures. Currie states:

> The idea of a picture needs no independent explanation ... (Currie, 1995, p.2)

The problem arises then if there is no picture, as in the abstract world of computational thinking, how does an individual construct non-linguistic knowledge? The use of metaphor and analogy has been addressed in Section 4.2 as one possible way of creating pictures for concepts that are not readily seen in the world. Data were gathered for this question within the construction of the prototype and through focus group discussions. A further iteration of the prototypes improved upon the pictures presented within the learning process.

Donis Dondis, a visual communicator and designer, also asserts that the construction of meaning involves " ... certain arrangements of the parts toward organising and orchestrating". She further states that meaning is observable and that " ... a visual message is channeled directly to our brain to be understood without conscious decoding, translation or delay" (Dondis, 1973, p. 106). Dondis makes reference to the fact that visual elements can have a "skeleton structure" (p. 104) composed through "enormous skill" (p. 104) to attain a purpose. Then the resulting composition undergoes a controlled reinterpretation " by those who experience it" (Dondis, 1973, p. 104). Although Dondis does not directly allude to Piaget's idea of schematic organisation within the brain, she clearly explains that the presentation of what is seen must be organised and arranged with great skill to attain the desired meaning. This organisation is imperative to the learning process and aligns with Piaget's definition of schema whereby a schema is the organisation of ideas in the brain. While Dondis focused more on the presentation of visual meaning, Piaget maintained that ideas are spatially arranged for the goal of creating meaning. Designers of communication artefacts that have an awareness of design elements and visual communication assist the organisation of schema for the beholder. The notion of representing information visually in space for the learner to discover meanings, given the sense of satisfaction in discovery, was a core objective of this PhD research. The following quotation summarises rare evidence of visible meaning and its relationship to design:

> Any visual event is a form with content, but the content is highly influenced by the significance of the constituent parts, such as color tone texture, dimension, proportion, and their compositional relationships to meaning. (Dondis, 1973, p. 15)

This quote begins to place the use of the picture in context within a group of other visual components. This quotation also illustrates the need to connect different types of thinking or ways of seeing. Pictures within this thesis have already been defined as physical artefacts. Mental models have been a well researched area of computer science and play a key part in the understanding of computation within the mind of a programmer.

Mental models and conflicting prior knowledge
Mental models are now discussed with reference to the concept of schema or organisation of knowledge within the brain. In Section 4.2.5 pictures were described by scholars as assisting in the creation of these models. Learners construct mental models and then build new knowledge upon the existing models established within their brains. The theory describing an individual's ability to construct new knowledge upon existing knowledge is constructionism. Although pictures assist in the creation of new knowledge, new knowledge can also conflict with a learner's existing mental models. Although the instrumentation in TOAOCP was designed to communication to all children, there was a group that didn't conform to the patterns revealed in the findings. An expectation failure in an individual, is a cognitive conflict whereby an attempt to explain new knowledge through existing structures leads to misunderstanding (Bain, 2004; Madden, 2011; Hermida, 2014). Information designers Michael Albers and Loel Kim, contend that complex knowledge in visual communication must serve the prior knowledge, or existing mental model, that the learner has established.

Connie Malamed also acknowledges the role of prior knowledge however relates this to recognition of a graphic. She states, "The comprehension of a particular graphic is dependent on a viewer's prior knowledge and ability to retrieve that knowledge" (Malamed, 2009). If what the user expects to see does not occur, then the type of communication may not transfer knowledge. The knowledge transfer is rejected resulting in an expectation of failure or conflict in the learner. In the article *Information Design for the Small-screen Interface: An Overview of Web Design Issues for Personal Digital Assistants*, the authors state:

> Ensuring activation of the proper mental model means that the information design must immediately establish an expectation of the reader response that fits with the reader's expectation. (Albers & Mazur, 2014, p. 54)

The quote above indicates that there is a disadvantage to using visual communication if it is not designed using the proper research, models and theories. TOAOCP reviewed a number of design theories and techniques before the construction of the instrumentation and milestones. Synaesthesia was also reviewed as there was not existing literature on using it for the purposes of communicating computer programming. The next section begins with a discussion about the work of neuroscientist Professor Vilayanur Ramachandran, an expert on synaesthesia and the way that the brain can create unique relationships between different regions.

TABLE 4.6: Diagrams and elements that influence cognition, Tversky (2015)

Devices	**Components**	**Theorists**	**Advantages**	**Examples**
Diagram	Marks and arrangements	(Donald, 1991)	Augment the mind	Altamira
Sketches		,Hutchins (1995)	Cognitive tools	Chauvet
Graphics		(Kirsh, 1995)	Cognitive artefacts	Apollo 11
Visualisations		(Malafouris, 2013) Spraction	Bedolina map	
Models		(Norman, 1993)		Trajan
Material		(Stjernfelt, 1911)		Titus
Gesture		(Suchman, 1986)		Valley of Kings

4.3.3 Synaesthesia

Synaesthesia is being examined within TOAOCP to explore shared perceptions that individuals may possess. Through examining these shared perceptions, my designs of learning programming were influenced (see Appendix A). If people do have commonalities when looking at a grouping, colour or pattern as in the gestalt principles, then it follows that there is a shared way of looking or perceiving things. It is this shared way of looking at things (Grundmann, 2001) that TOAOCP seeks to explore through shapes, colour and lines. Synaesthesia follows the schema section (see Section 4.3.2) because attributes within TOAOCP were used as synaesthetic percepts to encourage a learner to connect different elements that would not normally be connected. The design techniques used to encourage unusual schematic connections are discussed in detail later within this section. The discussion continues with a definition of synaesthesia and descriptions of its types.

Some individuals experience an effect called synaesthesia, where one sensory modality causes a reaction in another (Hubbard & Ramachandran, 2005). There are at least eighty types of synaesthesia some of which are:

- Grapheme-colour, where letters and numbers represent colours to an individual;
- Chromesthesia, where sound and colour are linked to spatial-sequence, and numerical sequences are seen as points in space;
- Misophonia, where negative emotions are triggered by specific sounds.

When more than one area of the brain is engaged, an irregular sensation happens, and a cross-modal convergence occurs. Neurobiologist Professor Semir Zeki (1999) noted that there was a consequence when looking at cross-modal interaction from both artistic and scientific angles. This effect, according to Zeki, is neuroaesthetic and may also assist in the topological organisation of thought. This acknowledgement of seemingly unrelated regions of the brain engaging is useful to graphic design.

Psychologist Wolfgang Kohler first experimented with cross-modalities or synaesthesia-type-mappings in an experiment with two shapes in 1929 (see Figure 4.41). The bouba kiki affect demonstrates mapping between visual objects and verbal sounds (Köhler, 1929). Particular sounds matched specific shapes.

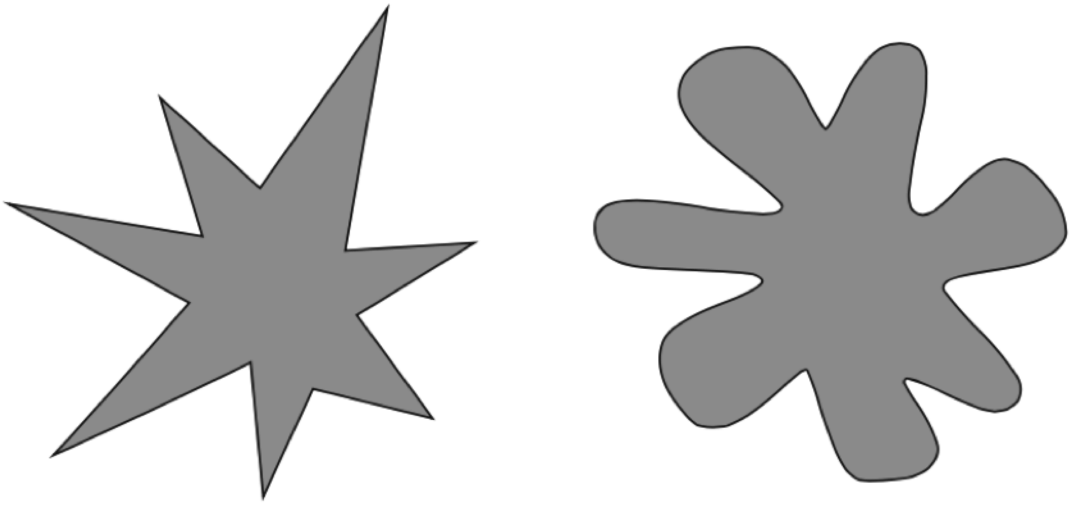

FIGURE 4.41: Kiki and bouba

Ramachandran and Hubbard replicated Kohler's experiments on synaesthesia later. Fifty participants were shown the two names of kiki and bouba and were required to match the words to the two shapes in Figure 4.41. These scholars repeated Kohler's experiment with a 95% and above proof that the left shape was kiki and the right bouba (Ramachandran & Hubbard, 2001). Although there is no area of the brain that has been designed to read (Wolf, 2017), there is evidence that the brain can relate between areas that are seemingly unrelated. The ability to relate between different areas is biological. The kiki and bouba affect was confirmed later in children as young as two and a half years old.

FIGURE 4.42: TOAOCP milestone colours

The bright colours were chosen for the milestones in TOAOCP to evoke a feelings of enjoyment (see Figure 4.42). According to colour theorist and academic Dr Zena O'connor, colour affects mood, behaviour and also encourages engagement (O'Connor, 2011, 2015; O'connor, 2018).

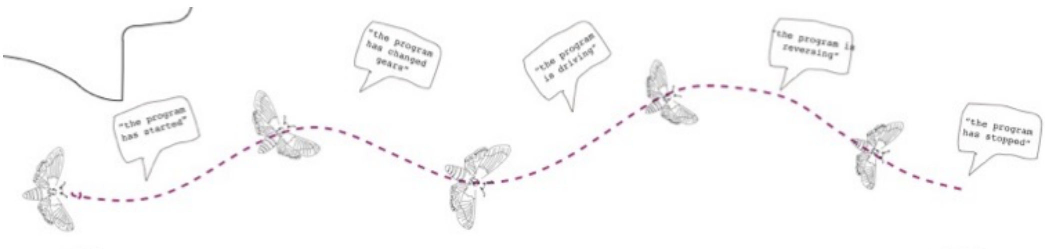

FIGURE 4.43: Data flow in milestone six

Wavy lines were also a deliberate choice used within milestone six (see Figure 4.43).The theme of data flow representing a dotted line was also revisited within other milestones (see Figure 4.32). The wavy line promotes informality that may relax a viewer experiencing any trepidation about a technical topic like programming. Round shapes, according to (Bang, 2016) invite engagement as they have a friendly feeling associated with them. Similarly the hexagons were used in the computational thinking pictograms in TOAOCP to symbolise symbolic order, repetition and relationships like that of a beehive (see Figure 4.63). The hexagon is a geometric shape found in nature and was also used to symbolise that computational thinking is often a concept that is not programmable.

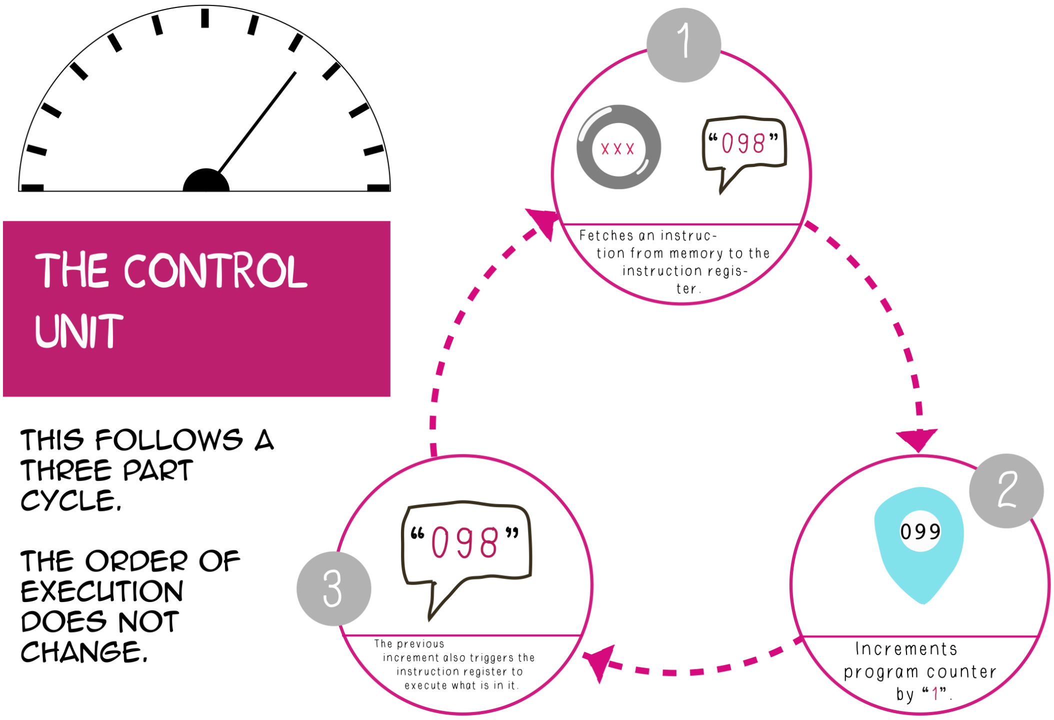

FIGURE 4.44: The control unit, milestone one, Von Neumann architecture

Circular shapes were used in milestone one to emphasize the continuous nature of the control unit within the hardware of the early assembler machines. Circles were also used to encourage familiarity as they are more likely to have shape-symbolic correspondence with sweetness as opposed to triangles which are angular and more associated with bitterness (Spence & Ngo, 2012). Computer hardware within the 1950s was seen as a very specialised form of engineering to be associated with. Circles are graceful and during the 1950s computer machines were prone to breakdowns and other maintenance issues. Circular shapes were used to offset and marginalise the major issues with hardware in the 1950s where possible in the first milestone (see Appendix A). The continuous nature of a circle in that it is a shape that has no beginning and no end was also used in the topic of recursion in milestone two (see Appendix A). Like synaesthesia, caricature is another design aspect I built into the learning materials of TOAOCP to encourage a biological response and enhance learning.

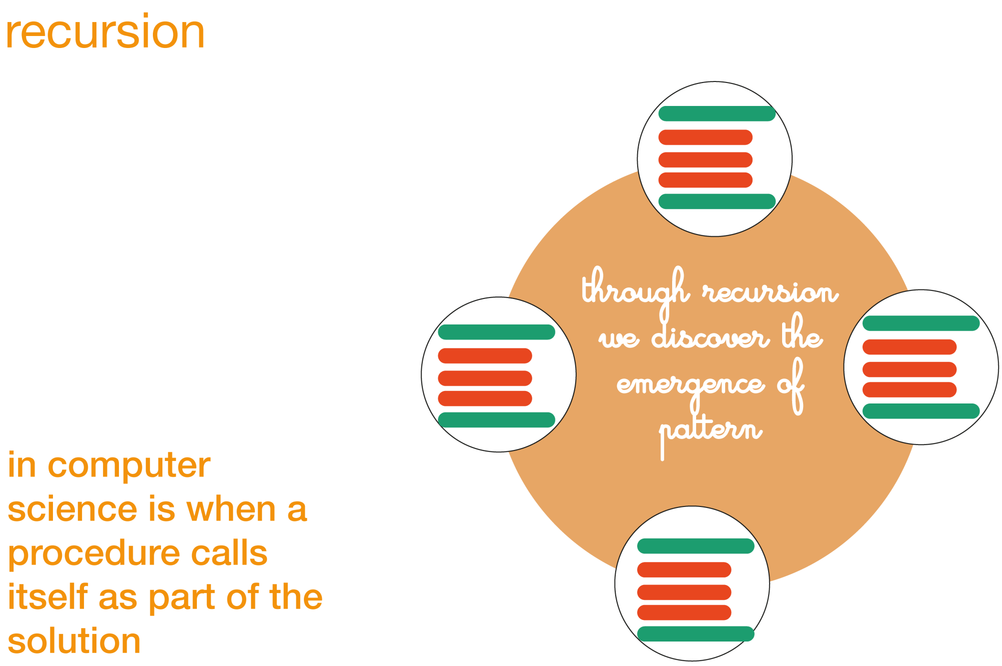

FIGURE 4.45: Recursion, milestone two

4.3.4 Caricature

Section 4.3.2 briefly mentioned that 'norms' are stored within the brain for purposes of recognition. These stored 'norms' are an important concept to understanding caricature. Caricature is briefly discussed within TOAOCP because in addition to the advantage of recognition, when caricature is applied as a design technique, information can be made much clearer for the viewer. Gombrich (2002) realised that this type of visual expression in the form of an exaggerated picture can connect to areas in the brain unrelated and evoke wit. Caricatures are often used to express feelings however within my research, caricature is used for purposes of clarity. Section 4.3.2 addressed how the brain organises thought through cognitive apparatus and that this is also a memory device and assists recall. A picture designed to be a caricature thus operates as a memory device and is useful in the learning process. According to Rhodes (1996) the cognitive apparatus of a viewer's brain matches visual information against the 'norms' as previously mentioned (see Section 4.3.2). By comparison to the stored 'norms', objects are recognised even though they may deviate from what a viewer's brain expects to see.

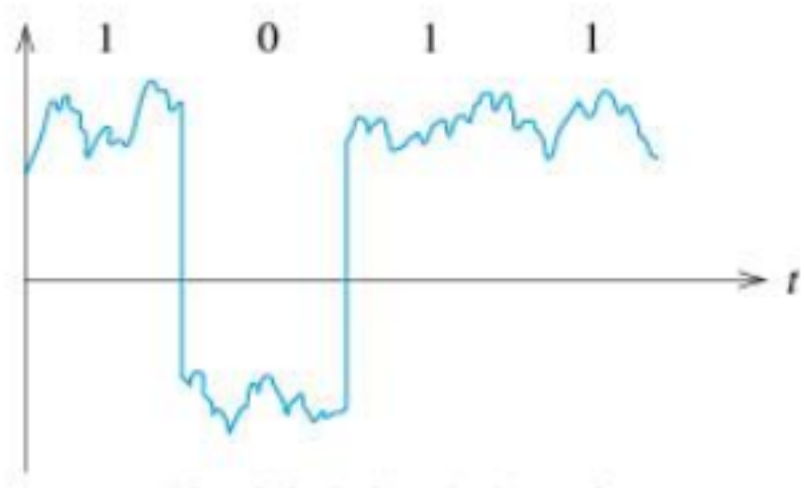

FIGURE 4.46: Real binary signal

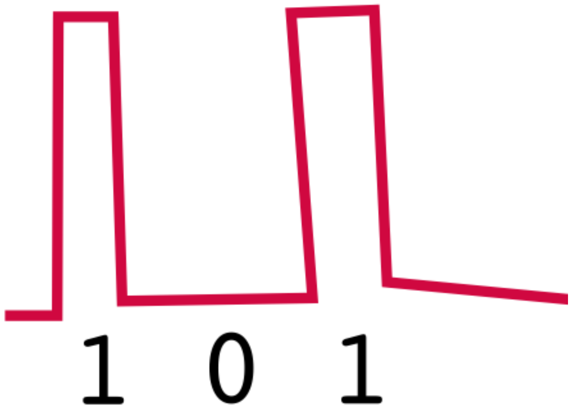

FIGURE 4.47: Caricature binary signal, Tarr (2018)

4.3.5 Visual perception theory

Perception and other affective factors this study considers

Gusta Britsch, a design artist whose research has applied to drawing pedagogy and children, describes how through direct perception, the mind strives to understand by the ordering of reality (Munson, 2015). This 'ordering' is achieved through a scan for a simple pattern, onto more complex patterns through the eye. Through the seeming chaos of nature, an order is perceived by the mind so as to create meaning. The ability of the mind to create order through visual perception was studied by Rudolf Arnheim a contemporary of Britsch who was a psychologist, artist and one of the major figures who established Gestalt theory. Through direct perception, the mind puts in order the natural world by utilising Gestalt principles (Arnheim, 1986). The Gestalt principles have been considered by programmers from a coding perspective however TOAOCP is pictocentric, placing the picture first. TOAOCP uniquely considers pictures in sequence, complex comic pannel-ing, dual coding and the representation of an entire program on one page. Some visualisation programming theorists (Sorva et al., 2013; Supli & Shiratuddin, n.d.) have also acknowledged a connection to the Gestalt principles, while Moons and De Backer (2013) pointed out visual perception and the Gestalt in the design of programming or "... visual program representation to help novice programmers" (p. 372). These visualisations apply gestalt from the programming perspective.

Building on Arnheim's theories, Piaget considered the development of an individual in stages.

TABLE 4.7: Stages of Cognitive Development, Piaget, (2015)

Stage	Age	Characteristics
Sensorimotor	Birth - 2 years	Experiences through movement and senses
		Egocentric
Preoperational	2 - 7 years	Transductive reasoning
Concrete Operational	7 - 11 years	Logical but concrete
Formal Operational	Adolescence and adulthood	Propositional thinking
		Hypothetics

Piaget's theory of cognitive architecture stated that a child begins to think abstractly, or hypothetically, as approximately the age of twelve (see Table 4.7). The following quotation from psychologists Brain and Mukherji (as cited in Cherry and Gans (2018)) explains the transition from concrete to abstract thinking:

> In the formal operational stage, actual (concrete) objects are no longer required and mental operations can be undertaken 'in the head' using abstract terms. For example, children at this stage can answer questions such as: 'if you can imagine something made up of two quantities, and the whole thing remains the same when one quantity is increased, what happens to the second quantity?' This type of reasoning can be done without thinking about actual objects. (Cherry & Gans, 2018, para. 6)

Reasoning without thinking about actual objects occurs in the formal operation stage. The formal operations stage occurs approximately at Year 8 level for each child and hence this year was the target population for my research. Most computer science programming occurs with elements that you cannot see. For example, you cannot see how the software works inside the computer. The ability of the student to think in abstract terms assists with the current methods of programming tuition.

According to Schwartz and Heiser (2006), there are four perceptual properties in imagery that help to construct a diagrammatic way of learning, as this assists building mental models or schemas. The properties are:

- Effortless structure;
- Determinism;
- Perception-action coupling;
- Pre-interpretation.

These authors also assert that use of pictures mimic perceptual experience, and therefore uses that move beyond this should be distinguished as there are different learning benefits in each (2006). The knowledge advantages of pictures in sequence, as images are structured, have been treated as a grammar and researched from a linguistic perspective that is not the objective of TOAOCP. Within TOAOCP knowledge transfer is measured through the learning of programming, utilises horizontal in contrast to vertical sequence of information.

Gestalt principles
Visual perception of a picture can be understood through the principles of Gestalt psychology, which is concerned with image processing and the human visual system. Gestalt means 'form' in English. According to Gestalt, our brains have innate organising tendencies. These biological tendencies structure elements, shapes and forms into an organised whole (Jackson, 2008). An aspect of Gestalt psychology explains how it is that we can perceive the whole object even by viewing only parts of an object. Organisation of information with the gestalt principles is not often made use of in formal learning by designers. Australian high schools do not use curriculums that use these Gestalt laws of perception to communicate programming. It is this gap that TOAOCP explores through practical application in the instrumentation and the milestones (see Appendix A).

Max Wertheimer, a founder of Gestalt theory, studied the visual problem solving abilities of landmark scientists such as Galileo and Einstein. Along with these observations, he also watched children solve mathematical problems. The essence of problem solving according to Wertheimer was being able to gauge the problem in its entirety. According to Wertheimer (1959) and concerning an individual's field of vision, a "field becomes crucial" and in focus (p. 212), however it is not isolated. Problem solving in essence involved two directions, the first was getting a whole consistent picture of the problem, and the second, the function of the whole and integration of the parts into the whole (Wertheimer, 1959). Some of the gestalt laws of perceptual organisation were applied to the milestones in TOAOCP and are given as examples later within this section (see Section 4.3.5).

Piaget explained that the brain understands the world through the organisation of elements or schemas (Piaget & Cook, 1952). It is by using the principles of similarity, continuation, closure, proximity, figure and ground that a visual and its meaning is considered first according to visual perception. Because I used a pictocentric approach in TOAOCP, the gestalt principles were necessary tools within the creation of the milestones (see Appendix A).

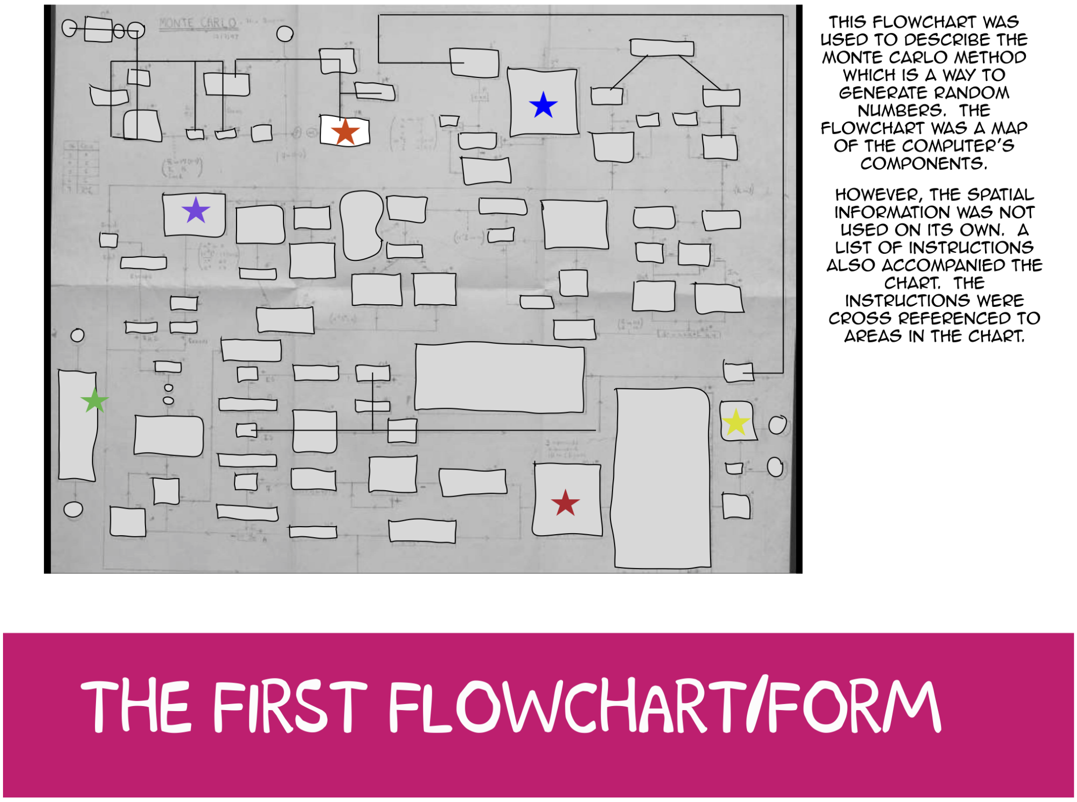

FIGURE 4.48: Overlayed monte-carlo subroutine

The gestalt principle of figure and ground was explored within milestone one to explain the origin of the flowchart as a diagrammatic device in computer programming. The original hardware of the subroutine (see Figure 4.48) was traced over and the machine parts of the map were indicated with stars. Figure 4.49 is a function of tracing over the shapes in the map.

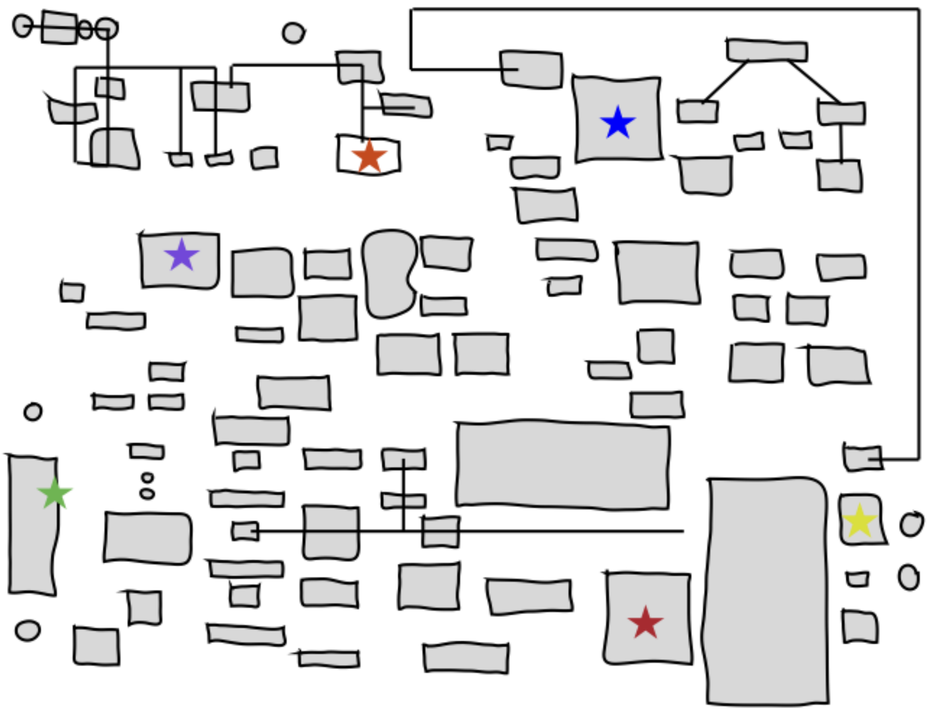

FIGURE 4.49: Figure of Monte-carlo subroutine - ENIAC

Software contains a finite set of patterns that can be programmed. Figure and ground was also used in milestone six (see Appendix A) to explain the one of these patterns called the decorator pattern. Figure 4.50 contains silhouettes that contain a rectangle inside. The interface is contained within the silhouetted mobile device. In this way, attention is drawn to the interface and the programming changes made by the programmer to the interface or screen rather than the hardware involved.

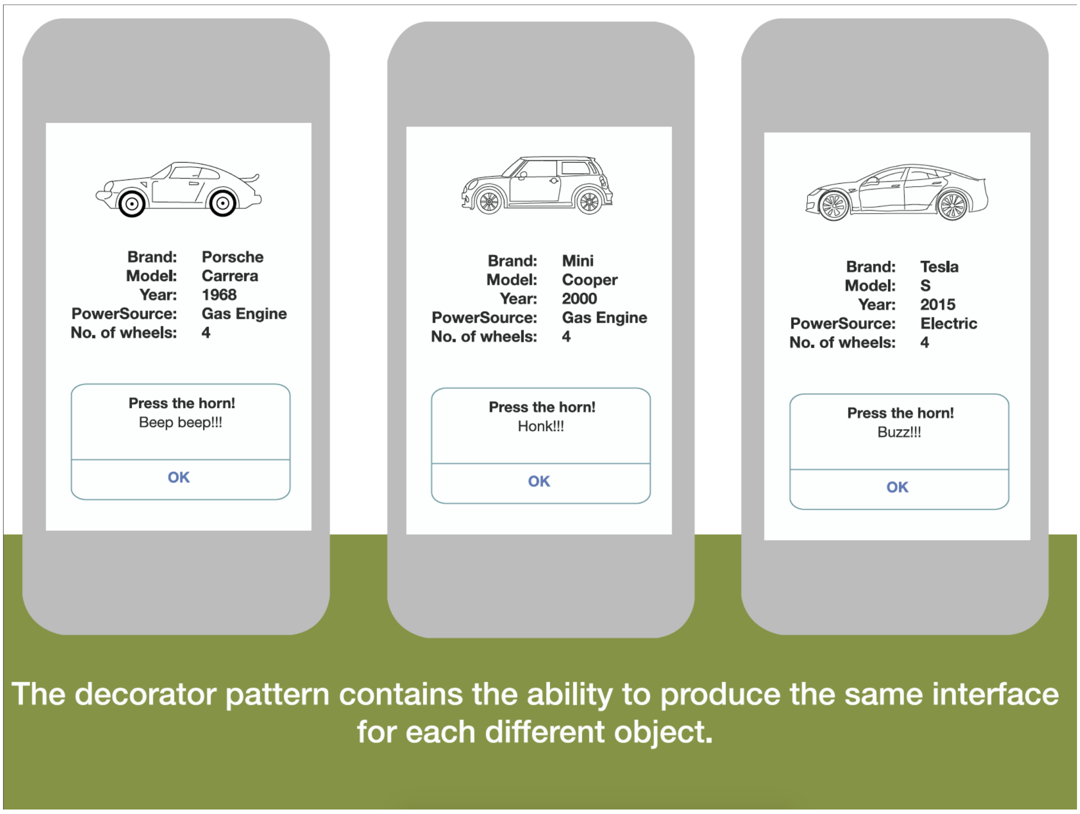

FIGURE 4.50: Use of figure and ground gestalt principle, milestone six

Objects and shapes that appear close together such as those in Figure 4.51 representing the instruction register for the Von Neumann architecture, appear as a group of the same element. The parts of instruction register, program counter and control unit make up the stored program concept or the Von Neumann architecture in milestone one and were enclosed in a dotted pink line for extra clarity.

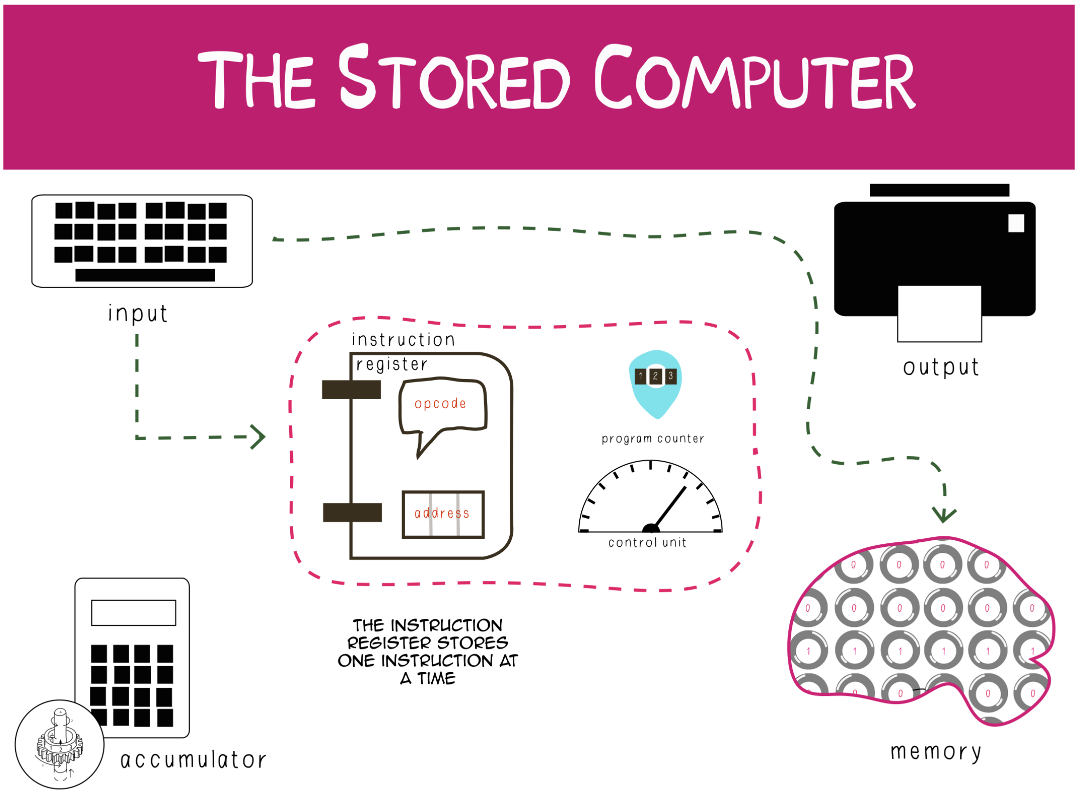

FIGURE 4.51: Gestalt grouping, milestone one

In their book, *Design Basics* academics and designers David Lauer and Stephen Pentak state the following about visual unity:

> An important aspect of visual unity is that the whole must predominate over the parts: you must first see the whole pattern before you notice the individual elements. Each item may have a meaning and certainly add to the total effect, but if the viewer sees merely a collection of bits and pieces, then visual unity doesn't exist. (Lauer & Pentak, 2011, p. 30)

Proximity, repetition and continuation promote visual unity. Figure 4.13 is an example of a program that draws a flower. Unity, proximity and grouping are used in Figure 4.13 where the entire flower is displayed before any of its constituent parts are. The petals are grouped in proximity to each other. According to e-learning designer Hamdani, Hosseinpour, Branch, Ahvaz, and Sharifuddin (2012), unity is an important digital design principle concerning e-learning packages and is seen as making the "text more understandable and the message simple" (p. 55). The enhancement of Flow Theory through the learner's appreciation of visual perception within learning materials has been not often been academically researched.

4.3.6 Flow Theory

The presence of flow in an individual when learning indicates a complete and energised focus in that activity. Being in flow contributes to a positive impact upon the engagement of a student when learning (Csikszentmihalyi, 1997, 2008a). Few studies exist that examine the affects of graphic design on learning and whether a flow effect can be experienced during visual learning.

Flow Theory concerns:

> Perceived challenges, or opportunities for action, that stretch (neither overmatching nor underutilizing) existing skills; a sense that one is engaging challenges at a level appropriate to one's capacities. (Nakamura & Csikszentmihalyi, 2014, p. 90)

Section 6.1.5 details the results of the flow factor testing in TOAOCP according to Csikszentmihalyi's theory. The participants evaluated their perceived compared to actual skill set. This evaluation of flow was the first measure of the impact of Flow Theory within TOAOCP.

Flow was also examined in TOAOCP because of the intrinsic control the participants experienced during learning through the pictures that were placed in sequence. Order and flow are connected to thought processes. Similarly, designer, painter and art theorist Gyorgy Kepes believed artists, through their creations could impose order on the information viewed to affect thought (Gyorge, 1965). Csikszentmihalyi believed this imposed order contributes to flow and the ability of the viewer of the information to focus. Therefore a second measure of flow was taken in TOAOCP to measure if the order of the pictures impacted upon the learning of the participants. I considered flow within TOAOCP to also enhance the holistic affects designed into the milestones (see Appendix A).

The principles of Universal Design for Learning (UDL) were also researched for holistic purposes.

4.3.7 Universal Design for Learning

Although attempts have been made to view learning from a visual perspective, holistic methods that combine both pictures and text appropriately within traditional education are not routine (see Section 4.2.5). The framework called Universal Design for Learning (UDL) uses cognitive neuroscience to construct a flexible learning environment that accommodates a broad range of learning differences (Rose & Meyer, 2002). I researched UDL before the milestones (see Appendix A) were created so the principles could be applied from a designer's perspective as previously discussed (see Table 4.10). This design for learning comes from a principle of inclusivity for all types of learners.

Inclusivity does not happen on its own and requires the correct design. TOAOCP seeks to explore where visual communication sits within the framework of TOAOCP. Using a holistic view, UDL appeals to three neural networks within the learning process. These brain networks are recognition, strategic and affective networks (see Figure 4.52). The recognition network processes sensory information and is situated towards the back of the brain. The strategic network is at the front of the brain and is responsible for action and response. The affective network processes and relays meaning and is located at the centre of the brain. These different networks in the brain were designed for within the framework of TOAOCP to inform the goals of the pictures used in the construction of the milestones (see Appendix A).

TABLE 4.8: Picture types and their affect upon brain networks

Picture types	Network	Features
Icons	Recognition	Categorize
Line art character	Affective	Preference, interest priority
Spatial arrangements		
Diagrammatic arrays		
Interaction elements	Strategic	Plan, monitor action

Within TOAOCP the affective networks of the brain were impacted. Section 6.1.5 discusses the impacts upon motivation, cognition and beliefs. Visual communication had a positive impact upon the affective networks of the brain indicating that visual communication is more than appropriate to be included in UDL. Table 4.8 suggests the picture types affected by the brain networks.

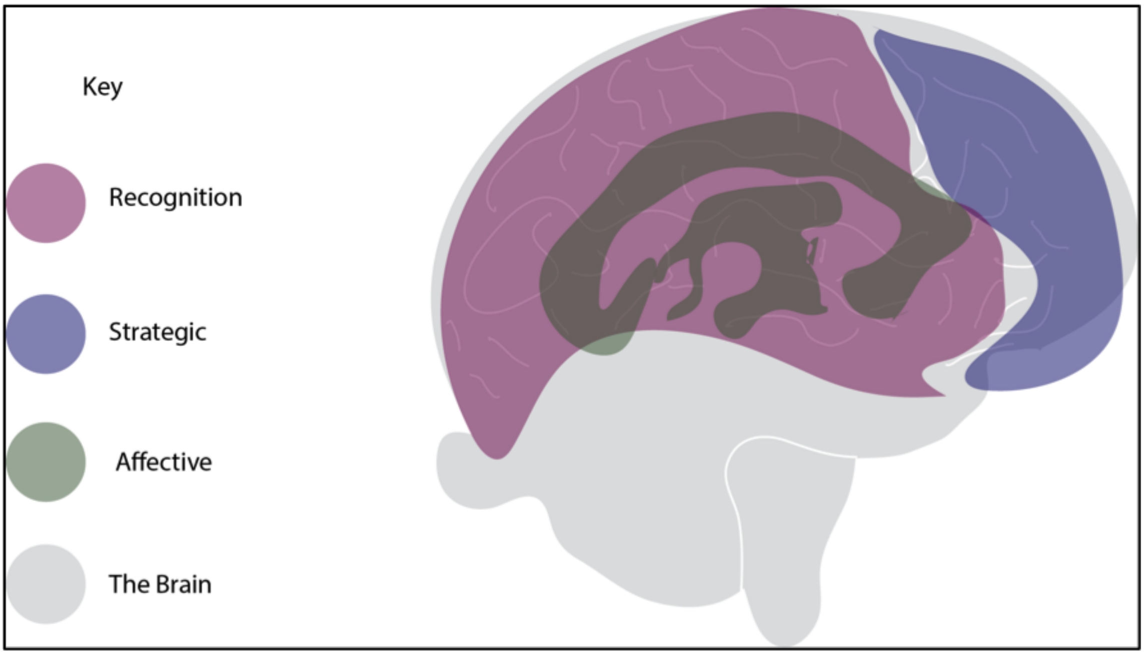

FIGURE 4.52: UDL learning systems

By considering the brain networks (as shown in Figure 4.52), I combined design elements in an artefact to align with the neural networks and other UDL guidelines. In this way, affective, recognition and strategic networks can be designed for through visual elements and then placed within the learning process accordingly. According to the principles of UDL, the brain consists of complex neural connections that are not mutually exclusive. The relevance of design here is that the interconnectedness of the brain is acknowledged within the practice of UDL principles by UDL educators. These brain connections all affect one another as, noted by medical researchers Kandel et al., (2002) who insist, "The brain consists of complex interconnected neural networks that are goal oriented, variable in their functioning, plastic and changeable over time" (Hall et al., 2012, p. 2). Other neuroscientists (Immordino-Yang & Damasio, 2007) state that "Cognition and emotion are interwoven and interactive" (Hall et al., 2012, p. 2). Education designers Glass, Meyer and Rose note the predominance of text and its effects upon the learning process:

> In recent centuries, schools have been dominated by a narrow set of representations - those that can be captured in printed books or on paper or blackboards. Text, in particular, is the easiest to capture in print, has dominated until very recently. That medium has been differentially successful, widening opportunities for some students and drastically narrowing opportunities for others. (Glass et al., 2016, p. 6)

Disciplines that are linguistically based tend to see pictures as an add-on to literary practice, a style within multi-literacy or a 'type' of learning, ie. visual learning. UDL frameworks on the other hand consider options for "perception...language and symbols ...as well as comprehension" (Hall et al., 2012, p. 107). These characteristics help to place text or linguistic learning within a more holistic framework that includes pictures.

TOAOCP's design measures the impacts of using pictures to learn computer programming. The impacts measured were self-assessed cognition, self-assessed motivation and attitudes (see Chapter 6). Despite the encouragement to adopt 'visual elements' because they have some effect on 'cognition' (Levin, 1981a, 1981b; Clark & Lyons, 2010; Lohr & Gall, 2008; Moreno et al., 2001) researchers look at placing 'visual graphics in text' (Hamdani et al., 2012) without however considering the visuals firstly on their own merit.

How pictures assist invention

A core area of cognitive science research is internal visualisation. The visualisation referred to is an individual's ability to represent objects, events and abstract phenomena as mental images (Hegarty, 2004). Many theorists support the role of pictures in assisting of the creation of these mental models and mind visualisations (Card & Mackinlay, 2001; Carpenter & Shah, 1998; Gordon & Pea, 1995; Larkin & Simon, 1987; Norman, 1993; Pinker, 1990). Researchers have noted the importance of simulating, imagining, or seeing an object before it exists in reality, from the point of view of design and invention.

Mental images led to the inventions of Nichola Tesla's hydro electric power plant at Niagra Falls, Oliver Evans' flour mill and Walter Chrysler's automobile company (Tesla, 1919; Ferguson, 1977). It would seem that the ability to visualise something that does not exist, also termed the 3rd type of vision as discussed previously, assists cognition. Students' ability to visualise is vital in STEM learning. The process of drawing or sketching by a learner plays a key role in the manifestation of many STEM ideas and inventions as well as the understanding of the concepts (Martin-Erro et al., 2016; Vukovic, 2016; Taylor, 2014). IDEO veteran and designer of the iPhone, Chris Stringer describes a design team's role as to "...imagine objects that don't exist, and guide the process that brings them to life" (Lowensohn, 2012). In support of the idea of product invention he also suggests products are formed by a process that evolves from sketching through to the final model or prototype. This section has highlighted positive ways drawing assists with invention and the flow of innovative ideas in a person's mind. However, there can also be barriers to learning that hamper invention and innovation.

4.3.8 Barriers to learning

Anxiety and information

In this section of the literature review I examine a theory of anxiety and review the impacts of this phenomenon upon the themes of cognition and motivation. Anxiety is a modern side effect of digitisation. The organisation of disparate information is a research area across the information design and information systems disciplines. Some graphic designers have also highlighted disparate information as an area of anxiety (Medley, 2013b; Wurman, 2000).

Marvin Minsky and Seymour Papert, in their foundational book on artificial intelligence, *Society of Mind* introduced 'Papert's Principle' : when there is confusion about types of information, then the person looking at the information will most likely choose the information that looks better or is aesthetically pleasing. In this way, the viewer of the information defaults to 'appearance' or what is perceptually easiest to understand. The principle could explain the high incidence of the participants in TOAOCP selecting *aesthetic* for the role of pictures within learning (see Figure 4.53). A high score for aesthetics in the data gathered during Research Phase Two would indicate support for this principle.

The overwhelming feeling felt by some individuals when receiving complex information can be lessened through diagrams and applying graphic design principles (Tversky, 2015). According to Wurman (2000):

> . . . information anxiety is produced by the ever-widening gap between what we understand and what we think we should understand. It is the black hole between data and knowledge, and it happens when information doesn't tell us what we want or need to know. (p. 14)

General anxiety was a focus within TOAOCP as visual design and communication are a mediating process that lessens to lessen anxiety. Consequences of anxiety include a negative influence on cognition (Morris et al., 1984; Philipi et al., 1972) as well as an impact on the acceptance of a new technology (Venkatesh et al., 2003; Kim & Rha, 2018). There are existing technology acceptance models (TAM's) that have measured anxiety levels in a learner (Durodolu, 2016; Hackbarth et al., 2003; Saade & Kira, 2009). Anxiety when learning, and information anxiety both remain a problem of the digital age.

A lot of information can be condensed into a single page by a designer. The pressure to locate or find information can hamper cognition and add to the anxiety an individual experiences. IBM researcher, Laura Hass makes a case for why finding information is so very involved. She summarises her explanation with the following statement:

> Why is information so hard to find? Partly, this is due to the increasing volumes of information available online. But there is a second, deeper problem, and that is the fragmentation of information, and the proliferation of information sources. (Haas, 2007, p. 1)

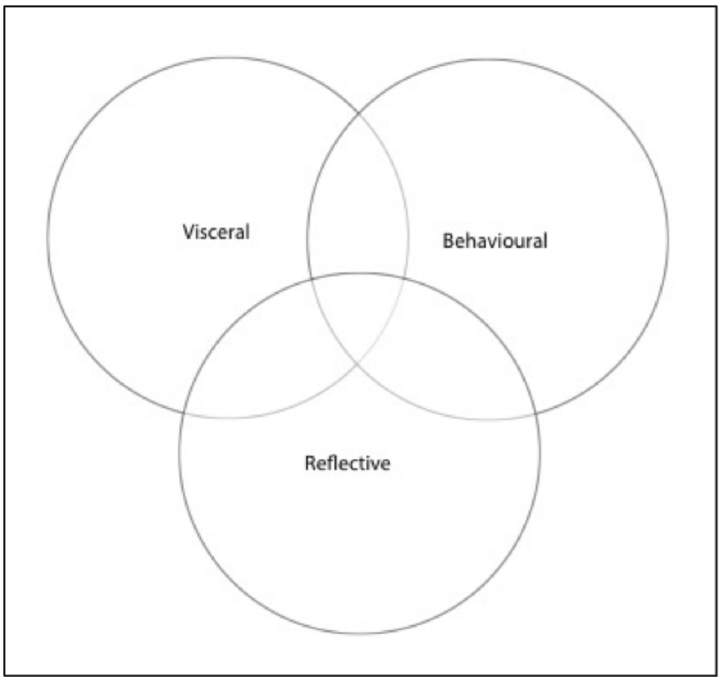

FIGURE 4.53: Norman's design levels

Pictures regarded as an aesthetic add-on to a learning artefact can work with or against an increase in cognitive load for the learner. For example, a student who is looking at pictures to learn will either understand or be conflicted about what the pictures mean. The visceral level of Norman's three levels of design (see Figure 4.53) can be out of balance with other levels. A graphic designer could employ the principles of visual perception to create meaning within learning and lessen the cognitive load that an individual experiences when viewing information. (Malamed, 2009) states that graphics of a low-fidelity kind, allow fast visual scanning and less information processing. Pictures with detail resembling the realistic require more cognitive activity of an individual's brain when processing (Berlo, 1960).

Along with the use of distilled pictures to lessen the impacts of anxiety, a designer can enhance salience. For example, the figure and ground gestalt principle can be used to make certain elements stand out from others (Glass et al., 1979). As the 'figure' stands out from the background, the information is recalled effectively (Abelson, 1985).

Rapid adoption of new technologies and learning

For teachers and students the pressure to adopt new technologies as soon as they are released has impacted on education. This pressure for rapid adoption means that the design of a system is often sacrificed or skipped as a cost-saving measure that causes significant problems for later software maintenance (Naz & Khokhar, 2009). Often, demand for either rapid or early adoption overrules the importance of a visual design within the learning. Careful consideration and long-range testing of 'The design of future educational interfaces', is often not an option as noted by industrial designer Sharon Oviatt where she states:

> Since today's schools are under increasing political pressure to demonstrate high achievement by all students, they are often eager to adopt technologies before assessment information is available that they actually improve student learning. (Oviatt, 2013, p. 2)

David Skopec, Chair of Visual Systems at the University of the Arts Berlin, contends, "... Digital media are often accused of having an innovative yet unstable disposition, not least due to their continuous technical advances" (Skopec, 2003, p. 114). This untrustworthiness or need for rapid adoption requiring added effort from the design affects the usability. The ethos form of rhetoric concerns the trust emotion. If an artefact is unstable and unreliable despite being innovative, the ethos component of rhetoric will be out of balance.

Professor Emeritus John Sweller is an Australian educational psychologist who formulated a theory of cognitive load. The pressure to learn new systems can often be a tradeoff with understanding actual curriculum content for novice learners (Sweller, 1999).

The literature review now examines the history of computer programming from its early conception as the embodiment of cognition in Alan Turing's machine, through to modern forms of digitisation. The many novice programming textbooks and software visualisations used to educate high school students are examined in the programming section (see Section 4.1.2). Milestones within the progress of programming are highlighted, and some are presented in visual form.

4.4 Ways of learning computer programming classed as "visual" from text to digital

The traditional documentation style and communication of computer programming concepts are the focus of this section of the literature review. The history of computer science is briefly discussed through mention of the key players and academic institutions that have played a dominant role in the education of the discipline. The discussion then addresses issues within the programming industry, and examines the predominant visual element (because no alternative has been examined) of communicating computer science learning - the screenshot. Pictures in computer science are classified, and two types of diagrams are reviewed, these are flowcharts and state diagrams (see Figure 4.56 and Figure 4.58). Flowcharts represent the logic of a program and show the transformation of the data that occurs as indicated by arrows, while state diagrams have shapes that represent transformations in data from beginning to end. Both flowcharts and diagrams contain a form and show its transition to another form. A flowchart explicitly states the navigation or the path the data travels as it transforms into information, and both represent the semantics, or in other words the meaning of the language or the coding constructs, as opposed to the syntax.

Section 4.4 reviews the techniques used to communicate computer programming and also examines some of the issues raised by computer scientists concerning programming education. Currently, screenshots and text appear to dominate the computer textbook landscape. Screenshots are particularly examined as they are prolific and little research exists about their abilities for effective communication (Horton, 1993; Van der Meij, 2000; Van der Meij, Karreman, & Steehouder, 2009). Research also does not exist about infographic design theory in the learning of programming. Diagrams within computer science rarely posses any realism. The use of pictures outside of a schematic variation on an idea is not predominant in the learning of computer science, that is, there is little perceptual information in the pictures that are used to communicate in this discipline. It is this representational or persuasive gap that TOAOCP addresses so as to allow learning to occur.

4.4.1 Reocurring patterns in computer science and evidence of picture-based communication in computer programming history

According to neurobiologists Professor Zeki and Nash (1999), " we see in order to acquire knowledge of the world" (1999), as an individual's brain has " ... mapped out a representation of a stable world of objects which is comprehensible and therefore negotiable in everyday life" (Broadhurst, 2012). These mappings in a person's brain acquire topological knowledge through sight. The topological knowledge of the child is tacit knowledge and can be assisted through illustrating representations such as relationships of proximity, separation, relationship of order and relationships of surrounding, continuity or discontinuity. According to geometricians, these spatial representations are topology (Piaget & Inhelder, 1956).

The methods for writing software have not changed significantly over the course of the last three decades (Graham-Cumming, 2013). There are a manageable number of concepts to learn in software (Graham-Cumming, 2013), and "...after programming for a long time you start to see patterns occur" (2013). Table 4.9 below is a compilation of what Graham-Cumming states as being the significant innovations of computer science. This analysis transpired during his talk on Turing's Curse (Graham-Cumming, 2013). Cumming maintains that despite the reinvention of concepts throughout computer science history since the 1950s; nothing is in fact original.

TABLE 4.9: Innovations in computer science, (Graham-Cumming, 2013)

1950s	**1960s**	**1970s**	**1980s**
Big data	Cloud computing	WIFI	GUI
Dietra's algorithm	Virtual machine hypervisor	Aloha net	Xerox 8010
MEMEX	Hypertext with clickable links	Ethernet Card	Apple Lisa
Hypertext	Markup language	Solid state disks	TCP/IP
	GML	Cray IBM mainframes instruction and Instruction	Smalltalk
	SGML		Occam
	Fibre Optic		

As a veteran now of the computer science industry I had long since suspected that computation concepts were actually reoccurring. This manageable list was compiled to assist the selection of some concepts that would be suitable for adolescents to learn. Selections from Table 4.9 informed the lesson selection that contained the treatment used in my research. I wanted to create a high fidelity ebook within a short time as part of the thesis. I also had to create a variety of short visual communications in the treatment that I could use to persuade novice programmers that they could learn programming. Many times I was told by computer science lecturers that the concepts I wanted to illustrate were too advanced for novice users. The way that mechanisation and digitisation occurs is not intrinsic knowledge, and the individual must learn how these processes work. I was sure this could transpire through drawing or illustrations of key concepts. Historicising the records of original inventions also gave an overview of the field (see Appendix F). The following section gives records of early computer science history.

Historically, computer science tuition has had a predominantly linguistic or text-based mode of delivery. Although online coding classes saturate the industry, sketches and planned diagrams remain rare especially in the field of computer education. Some scholars have noted that this is to do with a problem of visually representing space, such as in Piaget's seminal work, *Child's Conception of Space* (Piaget & Inhelder, 2004). This concept of visually representing space is important for computing tuition (see Section 4.4.1).

Piaget's early investigations into a child's psychological foundations of geometry are divisible into perceptive and cognitive functions (Piaget & Inhelder, 1956). Euclidean elements such as distance, lines, and parallelism were visualised by the child, according to Piaget and tested through drawings. At the age of three years, spatial representations or topology had emerged within the children. Poincaré, a mathematician, further elaborated on topology as presenting properties that are unaffected even if an object is deformed. It was through this appreciation of topology that Piaget understood that children had a high abstract appreciation of mathematics. In other words, non-linear or spatial representation holds meaning-making qualities for children. Drawing maps also assists the understanding of abstract concepts or concepts described by language as well as representational thinking. Thus the process of drawing for children assists in the revelation of meaning to them, and the fact that drawing and spatial representation coincide may help to explain the role of pictures in learning.

The role of pictures in learning was tested with the pilot group in this study, and is discussed in detail in Section 5.7. In short, within the pilot test, pictures were found to represent meaning and communication to the participants when they are learning computer programming (see Section 6.2.4). Additionally, the meaning-making ability of the pictures far outweighed their decorative or aesthetic effect.

Head designer of the award winning game *Monument Valley* Kevin Wong, attributes the game's success to having a strong emphasis on the appearance in contrast to the mechanics (Wong, 2016a). The pictures created for *Monument Valley*, according to Wong, have a high agency within the game, regarded as the inspiration for the design of the game and the reason for its success. An example is shown at Figure 4.54.

FIGURE 4.54: Monument Valley picture, permission to use figure

Wong's insistence that inspiration and success of the game are due to the pictures contrasts greatly with the conventions of teaching programming through text.

4.4.2 Major types of computer science communication that include pictures

The traditional way of learning the art of computer science is explained in this section along with an emphasis upon the holistic attempts made to communicate computer science by educators. Cambridge University in the United Kingdom delivered the first computer science degree in the 1950s (Ahmed, 2013). In America, Stanford University was the leading institution in the field and still possesses rich archives of its early teaching materials. The significance of the records will be discussed briefly in this section. A brief revision of online courses that offer computer science reveals they are predominantly linguistic with screenshots included as the content of the curriculums (Ching, 2014). The earliest forms of computer communication took the form of essay. The documentation concerning the Pascaline calculator is one such example. A description of this calculator reads:

> When a gear with ten teeth made one rotation (tens) a second gear shift one tooth until that gear rotated ten times (hundreds) that shifts another gear (thousands) etc. (Robat, 2014)

The above description represents the dominant, linguistic type of information that early and even more recent computer programming documentation employed. Although the texts for computing inventions are prolific, diagrams and plans are rare. However, plans and drawing do exist, and archived and locked away, many of these sketches communicate the necessary details that the text cannot communicate. Australian researcher Associate Professor Alan Bromley uncovered on of these artefacts at the Science Museum in London. This drawing was an original plan of Charles Babbage's analytical engine (Ahmed, 2013). The meticulous drawn plan by Babbage in the 1800s was used to recreate his machine - the Difference Engine II, 100 years later. Turing award winner and programmer Graham-Cumming states:

> Babbage left behind extensive documentation of the Analytical Engine, the most complete of which can be seen in his Plan 28 (and 28a), which are preserved in a mahogany case that Babbage had constructed especially for the purpose. (Graham-Cumming, 2013)

Once Babbage's drawing of the Difference Engine II (DE2) was discovered, the plan was interpreted and rebuilt in its entirety by computer historians Graham-Cumming and Dr Doron Swade. During my investigations in Research Phase Two, I found that Swade confirmed that the sketches (see Figure 4.55) were essential to the construction of the engine (Babbage, n.d.). The following quote is from Swade on the importance of the Difference Engine Two (DE2) sketches:

> The construction of DE2 was based on some twenty technical drawings left by Babbage. Without these the construction would not have been possible. (Swade, 2016)

Babbage's drawing greatly assisted the third type of vision here – 'the imagined but as yet unseen or unproven', as discussed earlier (see Section 4.2.1). Through the drawings engineers were able to follow Babbage's plans drawn 100 years before to reconstruct his engine with few alterations. This third type of vision was discussed thoroughly in Section 4.2.1 so as to place this research within a visual communication context. Through all discussed above it is clear that diagrams and pictures play integral roles in the formation of new knowledge.

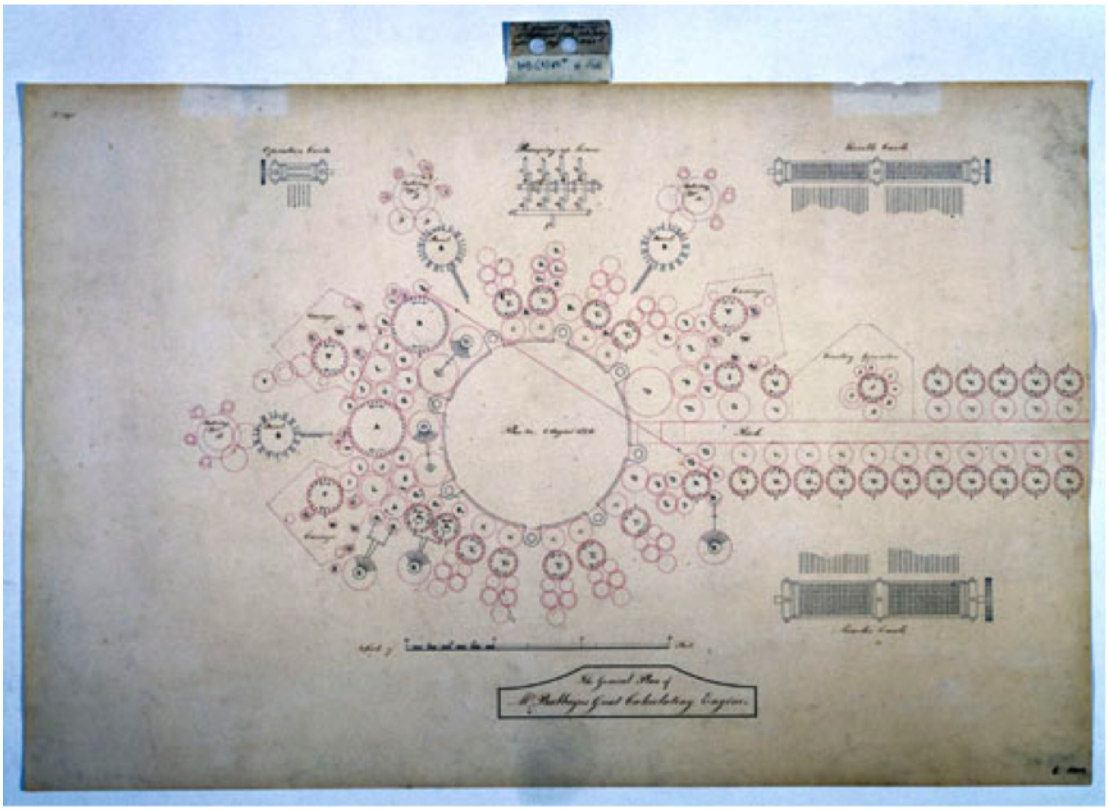

FIGURE 4.55: Engine sketch, Babbage (1800s), Used under Creative Commons License 4.0

Another such example of hidden visual documentation can be found in the library archives at Stanford University. These hand-crafted documents are not available to the general public despite the numerous references to them in computer science texts. It is unknown as to why computer scientists consider pictures as being non-essential pieces of information transfer. Professor Knuth states:

> Scholars can look at the handwritten pages that led to Volumes 1–3 [Knuth is referring to the original handwritten notes of the volumes - *The Art of Computer Programming*] by going to the Stanford Archives, and all of the remaining pages will be deposited there eventually. I see little value in making those drafts more generally available—although some of the material about baseball that I decided not to use is pretty cool. Archives from the real pioneers of computer science, who wrote in the 40s and 50s, should be published first. (Bentley, 2014, para :11)

Despite Knuth's view that he is not 'artistic', there is a plethora of non-linguistic communication within his book volumes - *The Art of Computer Programming* (Knuth, 1997). Diagrams often are better at revealing the thought processes of their creator as sometimes in the process of transferring these drawings into a digital delivery their meaning somehow changes. For example, the original flowcharting diagrams created by early computer scientists are radically different from their current form. Turing's flowcharts were horizontal, and Von Neumann's were often cyclical as opposed to a 'modern' flowchart that follows a vertical listing (see Figure 4.57). Diagrammatic affordance is defined and discussed later, however, it is worth noting now that there is specific meaning associated with a picture once it has been recorded on paper. Time-ordered information in computer science is often communicated vertically to follow machine code, as opposed to the original way that information flow was intended to be conveyed. This indicates that at some stage the flowcharts changed to reflect the technology.

Text is a linguistic mode of communication that is prolific within computer science publications. The approach within TOAOCP was to examine the visual side of the discipline as well as other holistic aspects. Pictures and visual communication replaced linguistic documentation to communicate with the target audience. Through graphic design, I wanted to impact beliefs as well as have both a cognitive and motivating influence upon the participants (see Chapter 6).

The definition and scope of digital literacy are addressed in the next section along with suggestions from computer science scholars to improve the way computer programming is communicated.

4.4.3 Coding as a general skill under digital literacy for a wide range of abilities

Computing academic Paul Denning states that computer science needs change in order to open the knowledge of the discipline up to areas outside of itself. By using pictures that appeal to a wide range of viewers, the change Denning advocates for could be hastened. Denning comes from a computer education perspective and places the discipline of computer programming within science. He asserts that computer programming has a specific role within computer science as a whole and rationalises that people outside the profession also require an understanding of how it operates. Denning cites four key ideas as the basis for immersion within the profession; these will be reviewed within the thesis to form a basis for the artefacts produced in Research Phase One, Two and Three of TOAOCP. The four ideas are:

> What is information?
>
> What is computation?
>
> What can we know through computation?
>
> What can't we know?
> (Denning, 2015)

Denning further states:

> The discipline of computing is the systematic study of algorithmic processes that describe and transform information: their theory, analysis, design, efficiency, implementation, and application. The fundamental question underlying all of computing is, 'What can be (efficiently) automated?'
> (Denning, 1997)

Denning's perspective is important within the context of this work because he considers computer science holistically and empathises with users outside of the discipline who desire the knowledge of how programming intrinsically works. For example, designers and occupational therapists may need to understand what can be programmed and what cannot, particularly in the case of mobile application development. The initial results of TOAOCP were that the average student's beliefs and values about learning computing could change through the use of visual communication and graphic design (see Chapter 6).

Programming has only recently (2016) been included within the high school environment under the Australian National Curriculum. Although all Australian schools are asked to comply with the Curriculum, they have flexibility due to religious and cultural reasons of how this is done (ACARA, 2019). A full examination of the variants of this compliance process are outside the scope of TOAOCP. Digital literacy is a term that has long associations with the tools of technology and their use compared with how that technology functions. Knowledge of computer programming is coded and contextual, a fact highlighted later in a discussion between cognitive scientist Distinguished Professor George Lakoff and documentation writer Chris Espinosa (see Section 4.1.2).

TOAOCP puts programming under the definition of digital literacy and aims it at the Year 8 adolescent. There is currently a lively debate as to whether digital literacy should even include programming. I am reviewing Denning's perspective on what should be in an early curriculum that promotes digital literacy according to how persuasive graphic design can be. This scholar situates programming firmly within digital literacy. The project objectives have been adopted from *The Great Principles of Computing* and provide effective scaffolding by which to build the framework of this project. These are:

> It is important to collaborate with people outside the field particularly in the natural sciences.
>
> It is important for innovation in other disciplines to understand that solutions from computer science are available.
>
> Fields overlap in occupations and it is important to be able to answer questions in other fields with information technology.
>
> In order for the advancement of science, we need a common language to discuss the application of computer science in all disciplines.
> (Denning & Martell, n.d.)

The above objectives indicate that digital literacy includes a wider range of disciplines and personality types than are currently the ones most commonly engaged in it. Another notable programmer, who has discussed a common language in order to apply computer science to information issues in other disciplines, is the inventor of the programming language C++, Bjarne Stroustrup (Stroustrup, 2011). This programmer asserts that 'guidelines' are necessary, although Stroustrup comments on this from an interdisciplinary perspective between the languages. TOAOCP aims to place pictures within this unified language as part of its communication.

Bill Thompson's lecture at Cambridge in 2009 on the *Two Cultures Problem* considers "...what level of understanding of computer science is needed to be an effective and engaged member of modern society" (Thompson, 2009). Thompson's views are also important to this PhD research because he highlights the need to integrate art and science in regards to programming and he also links integration to understanding. Thompson, who possesses a diploma in computing, sees the division of science and art as being related to "those that understand code and those who can't" (2009). Knuth, also asserts that there should be less division between those people who can program and those people who do not. Most of the participants scored 66% in the knowledge test for TOAOCP (see Figure 6.15) and the aim of most participants understanding the visual communication within TOAOCP was achieved. Although many of these students may not become programmers, now they have a better understanding of the concepts of computer science. They may also find it easier to apply these concepts to the respective disciplines of their studies. Perhaps the most noted academic advocating for changed within computer science education is Professor Donald Knuth.

Computer science can suit a wide range of abilities

Professor Donald Knuth contends that computer science suits a broad range of abilities. Knuth wrote the left-right (LR) parser, a type of compiler in 1965. This researcher is still working at Stanford University on his volumes titled the *The Art of Computer Programming*. These volumes are seminal references and cover a range of necessary knowledge in the discipline. In stating that computing suits a wide range of abilities, Knuth affirms that therefore inclusivity of these abilities should be apparent within the learning materials (Knuth, 1997); pictures are a possible way to do this.

Denning refers to the developments in computer science as being inspiring and also asserts that we should "Develop new approaches to teaching computing that inspire curiosity and excitement" (Denning & Martell, n.d.). Both Knuth and Denning mention narrative throughout their writings, with Knuth believing that programming should be a good story read by many differing levels of ability (Knuth, 1997). There are numerous references to the idea of computing being interdisciplinary throughout both scholars' works. Denning further believes that computing needs to "Establish a new relationship with people from other fields by offering computing principles in language that shows them how to map the principles into their own fields" (Denning & Martell, n.d., para :11).

Furthermore, these scholars are not the only computer science educators who encourage collaboration with other disciplines. The goals and motivations of researchers looking at multi-modal technology to teach computer science concepts has aligned with the developments of new media. Problems concerning algorithms, artificial intelligence, algorithmic data structures, digital architecture, statistical systems, operating systems, coding languages, software engineering and geometry are learnt through software processes (Balci et al., 2001; Garcia et al., 2007). The focus group discussion results in TOAOCP highlight the specific findings upon video and the learning of coding within the qualitative research results (see Section 6.3.14). Clark and Mayer (2016) state that animation "...presents a great deal of visual information in a transitory manner" (p. 165). Further to this Clark and Mayer (2016) provide evidence that a series of static line drawings viewed one at a time is more effective than an animation that uses the same drawings (Butcher, 2006; Clark & Mayer, 2016; Mayer et al., 2005b). Examples are provided in Scheiter et al. (2009) where realistic videos fail to enable comprehension compared to static visuals for students. Videos and animations may not encourage deeper learning of computer programming concepts (see Chapter 6, Section 6.3.14).

Seminal researchers assert that presenting information through multimodal processes increases cognition as well as motivation (Bell et al., 2014). The learning process of a student is influenced by their cognition and motivation, as well as other less measurable affective factors (see Section 6). Although multimodality is the reason for the increase in the learning factors, explicit testing on each of the features within multimodality does not routinely occur within programming research. The reason there is a change in the motivation and cognition where multimodality is concerned is because of the introduction of sequence and the fact that the media is image based, so it is a visual step-by-step process making the programming seen.

Affective factors such as increased motivation in learning now appeal to many different types of educators. Frameworks such as Universal Design and Learning (UDL) appeal to an extensive and diverse range of students (NCSU, 2008). The discipline of graphic design fits well in this theory within the context of learning (CAST, 2011; Glass et al., 2016, 2013). Under the UDL guidelines the following points are satisfied by TOAOCP research (see Table 4.10). Multiple means of representation occur during the Milestones in Appendix A by presenting picture and programming code together within panels. A range of iconography, mathematical expressions, symbols, pictures and text are presented within the Milestones. Pictures also communicate across languages, for example, the picture of a telephone can be recognised by a native Japanese speaker and an English speaking person. The milestones make use of narrative design and iconography to highlight patterns features and relationships between them. Diagrams within computer science do not focus on the topics examined within this literature review such as narrative, iconography or metaphor.

TABLE 4.10: UDL guidelines in TOAOCP

Provide multiple means of representation	Design elements
1. Provide options for perception 1.1 Offer alternative for visual information	Pictures and code together
2. Provide options for language mathematical expressions, and symbols 2.4 Promote understanding across languages 2.5 Illustrate through multiple media	Iconology, pictures and text
3. Provide options for comprehension 3.1 Activate or supply background knowledge 3.2 Highlight patterns, critical features, big ideas and relationships	Narrative design, iconology, repetition of picture use throughout lessons to build

4.4.4 Diagrams in computer science and picture assembly instructions

Diagrams used in computer science to describe processes and information, range from Unified Modelling Language (UML) through to state diagrams. The two previously mentioned diagrams, flowcharts (see Figure 4.56) and state diagrams (see Figure 4.58), use shapes and are contextualised or need pre-existing knowledge to understand them. There is no way to understand the meaning of the diagrams on their own apart from reading the text that accompanies the shapes. The following section reviews two popular diagrams used within computer science.

Visual representations of the processes and data manipulation within computer science exist within programming textbooks (Bansal, 2014; Bromley, 1982; Knuth, 1997). These are used to represent the different processes that occur from the design of the software, to the behaviour of a system and to the activity that occurs within it. A review will be conducted in this research project on two major existing representations, as in flowcharts and state diagrams.

Flowcharts are used in software engineering and programming to represent processes and algorithms. These flowcharts consist of a diagram or schematized representation containing shapes, words, arrows and lines that model an answer to a programming problem or process (IEEE, 2018). The following is a flowchart that could be used in computer science to explain the operations of a simple machine.

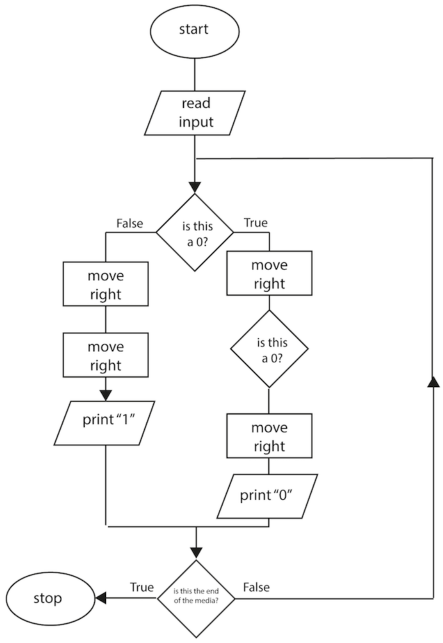

FIGURE 4.56: An example of a flowchart

The shapes within this flowchart are ellipses, rectangles and diamonds. The ellipses are control blocks or start and stop instructions. The diamonds represent decisions, and test if this program reads a "1" or a "0" from its input. The rectangles represent a moving operation and output. The moving operation positions the machine in its correct state and the output prints the information. When programmers are designing code, some will use flowcharts to represent the initial idea. Normally after a flowchart is designed and tested then pseudocode and algorithms may be written. Pseudocode is specifically structured English that describes an algorithm (Nishimura, 2003). Following this process, the code is constructed out of a high-level language such as Java, C or Python. Data is then used to manually check the function of the flowchart and this may be carried out using pencil and paper. Pseudocode for the Figure 4.56 would read as follows:

START.

IF you are in at the first square (M0) and are scanning 0,

MOVE RIGHT

Change state to MovedOnce (M1)

IF you are in at the first square (M0) and are scanning 1,

MOVE RIGHT

Change state to MovedTwice (M2)

IF you are at MovedOnce (M1) and are scanning 1,

MOVE RIGHT

Change state to MovedThreeTimes (M3)

IF you are at MovedOnce (M1) and are scanning 0,

MOVE RIGHT

Change state to MovedFourTimes (M4)

IF you are at MovedTwice (M2),

MOVE RIGHT

Change state to MovedThreeTimes (M3)

IF you are in MovedThreeTimes (M3), PRINT-1 THEN STOP.

IF you are in MovedFourTimes (M4), PRINT-0 THEN STOP.

In summary, a flowchart maps the time ordered series of steps that a program executes. Within TOAOCP time ordered sequence is drawn from left to right with a series of pictures. These sequences, as discussed earlier in this review, are also used within visual communication to illustrate time ordered activities (Boreczky et al., 2000; Legrady, 2000). However, unlike flowcharts, comics have maintained their Z-path or the left to right transition with the reading sequence, like the original flowcharts of Turing and Von Neumann (see Figure 4.57). Turing's flowcharts were hand drawn left to right well before the code for the Turing Machine was written. The drawing process came from Turing's thoughts and was not influenced by any machine implementation.

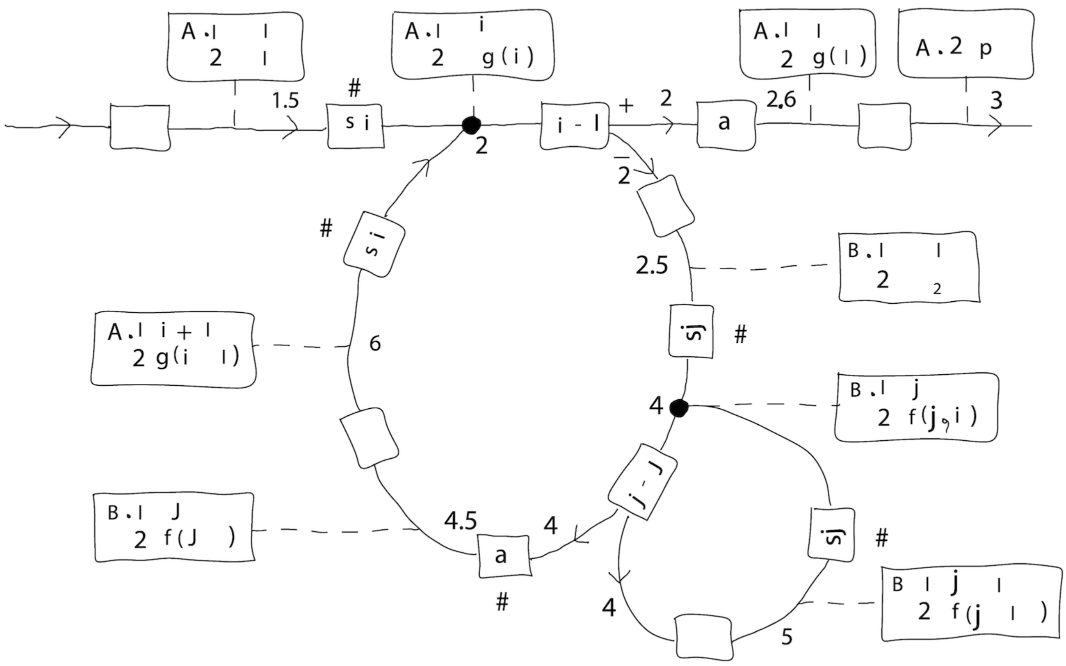

FIGURE 4.57: Von Neumann flowchart (Adapted from Haigh, Priestley, Rope, 2014)

Flowcharts are mainly used to represent process and activities that are in succession (Havey, 2005) and they differ from a state diagram in that they visualise behaviour (see Figure 4.58). The state diagram in Figure 4.58 shows a simple task of opening a closed door, repeated. The state that the door is in can only be 'opened' or 'closed' and this is represented by the circles. The arrows show the transitions to the two states, as they represent the act that a person performs. These actions are the transition conditions.

There are some ways this diagram presents that would not work in the milestones. I wanted to follow any time ordered operation from left to right with a clear entry point being on the left. I also intended to replace as many words as possible with pictures. Once a time-ordered representation of information flow was hand-drawn in an early lesson, it was classed as a thematic device and carried through in a similar format to later lessons. At this stage, I was also curious why computer programming flowcharts (see Figure 4.56) followed a vertical direction as opposed to the convention of time ordered information flowing from left to right, so I reviewed the history of flowcharts.

One of the earliest forms of a flowchart is in the publications of Alan Turing containing no text, but only mathematical symbols (Turing, 1984). The reproduction of the flowchart followed the standard Western time-ordered convention of going from left to right. The modern convention is instead to start at the top of the page and progress to the bottom. The orientation of the diagram changed over time from a landscape one to a portrait orientation. Time-ordered information suddenly went from top to bottom of the page instead of left to right. The data flow followed the technologies of the vertical presentation of code. In the time of the 1930s, rather than design a complex instruction set for a machine that did not yet exist, Turing followed a line of thinking that embodied thought through logic.

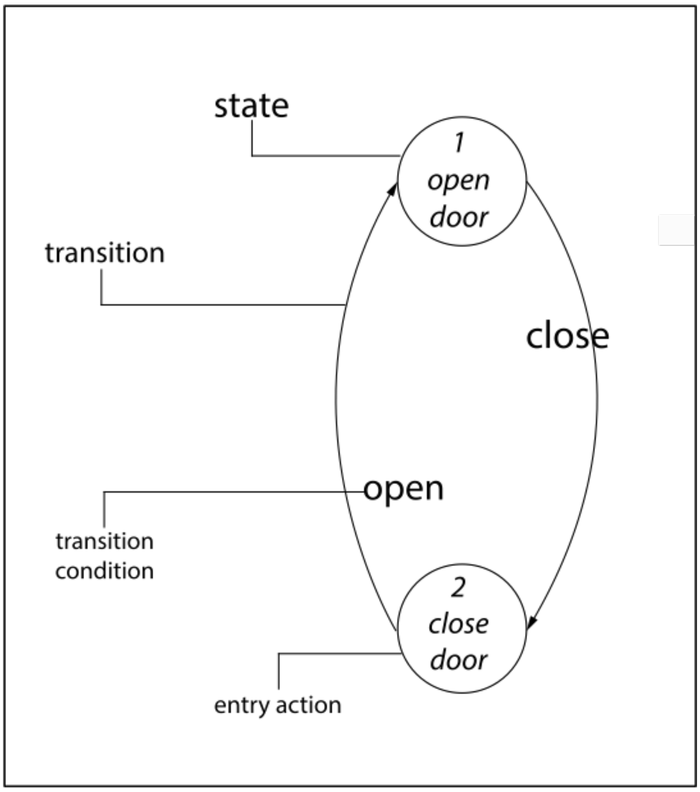

FIGURE 4.58: State machine diagram

At the time of Turing's work, in the 1930s, many researchers were attempting to formalise a theory of human knowledge (Davis, 2001). Among these logisticians were Leibniz, Boole, Frege, Cantor, Hilbert and Godel. They were searching for a logical expression to transfer into an algorithmic process. The expression would be computable or be able to be automated. A state machine diagram is a representation of a problem-solving theory that is a diagram (see Figure 4.58). The names of other common diagrams used in computer science are given in Table 4.11.

TABLE 4.11: Design elements and diagrams in computer science

Topology	Sequence Flow	Hierarchy classification	Association	Cause and effect	Logic reasoning
Conceptual models	Flowcharts	Organisation charts	Entity relationship diagrams	Fishbone diagrams	Decision trees analysis
Network diagrams	Activity diagrams	UML diagrams		Fault tree analysis	

A brief explanation of flowcharts and state diagrams is necessary as they contain components that are contextual. Universal markup language (UML) activity diagrams are also featured as they are a combination of both flowchart and state diagram. Because of their hybrid format, they can represent general processing patterns within computer programming. Activity diagrams have been criticised as "... lacking the clarity of the state machine" (Havey, 2005, p. 69). Reviewing the criticisms of these types of diagrams, along with their particular design elements, is necessary to answer Research Question One concerning cognition.

Evidence of picture use in engineering - pictorial assembly instructions
This deals with pictures in sequence with text instructions. Used by Lego and Meccano among other brands, these artefacts are called picture assembly instructions (PAIs). PAIs have been included within the computer programming section as an example of technical documentation where the picture is fundamental to the layout. PAIs are commonly used to help a person perform an assembly task. The task can range from constructing a piece of furniture to a jigsaw puzzle to a paper plane or even to the assembly of a car engine. PAIs consist of different types of diagrams - action and structural - where the action diagrams depict the parts that are about to be connected, while the structural diagrams show the parts in their final configuration. In contrast, within TOAOCP the states of representation as dictated by code statements or groups of statements were drawn and placed in order from whole to parts. The final state was placed at the beginning of the panel sequences within TOAOCP and the whole came first (see Figure 4.12). These states of representation were then ordered to explain programming operation.

PAIs are visual instructions where the nature of assembly is complex, the users come from different language groups thereby precluding the use of text (Schumacher, 2011). The nature of assembly here are picture sequences. Peter Schumacher's thesis acknowledges a gap within the research of PAI designs and more specifically, the useful illustration of these artefacts.

Furthermore, he also notes there is rarely any academic discussion of the comprehension of illustrations by users within his area of research (Schumacher, 2011). Schumacher also cites a list of features from a study performed by Professor of computer science, Maneesh Agrawala and other experts that are helpful for pictorial assembly creators (Agrawala et al., 2003). This study linked spatial ability to an individual's ability to assemble an object. Table 4.12 gives a summary of the features suggested by Agrawala et al. (2003).

Using Table 4.12 as a guide, I constructed my own set of guidelines and referred back to these throughout the thesis. My guidelines are listed in Table 4.13. I used the panel segment beneath the picture of the information to display programming (see Figure 4.15). Ideally, I wanted to include the pictorial representation, the coding, and a brief explanation of the coding if necessary.

Figure 4.59 shows the idea to incorporate arrows within a lesson on programming. Here one side of the flower petal is drawn before the other. The arrows follow the order of the code execution. Figure 4.59 combines gestalt theory and programming to build on the

TABLE 4.12: Guidelines to produce PAIs, (adapted from Schumacher, 2011a)

Item	Feature	Theorist
1	Step-by-step diagrams	Agrawala et al. (2003)
2	Clear and explicit ordering of the steps	Agrawala et al. (2003)
3	Parts added in each step should be visible	Agrawala et al. (2003)
4	The mode of attachment of the parts should be visible	Agrawala et al. (2003)
5	Action diagrams are preferable to structural diagrams	Agrawala et al. (2003)
6	Arrows and diagrams should be used to indicate how the parts are attached	Agrawala et al. (2003)
7	Illustrations should be in perspective	Agrawala et al. (2003)
8	The view of the object between steps should not be changed	Agrawala et al. (2003)
9	Objects should be shown in a gravitationally stable manner, how they would appear if arranged in front of the viewer	Agrawala et al. (2003)
10	Parts within a group should be added to an assembly at the same time or in sequence with one after another	Agrawala et al. (2003)
11	Attachment operations are seen as a hierarchy of operations on the parts	Agrawala et al. (2003)
12	Most objects have preferred view that maximises visible features	Agrawala et al. (2003)
13	New parts added need to be visible and also parts attached earlier to contextualise the information	Agrawala et al. (2003) Szlichcinski (1984)

TABLE 4.13: My adapted guidelines for learning programming with pictures

Item	Feature	Initial Example
1	Step-by-step pictures that show accompanying executable code	Figure 4.12
2	Clear and explicit ordering of the steps	Figure 4.12
3	The coding for parts added in each step should be visible (calling abstraction)	Figure 4.12
4	The coding of each part should be visible (abstraction steps)	Figure 4.12
5	Final state diagrams are preferable to prior states	Figure 4.13
6	Arrows and pictures should be used to indicate how code executes	Figure 4.14
7	Pictures need not be in perspective nor be of a real object (can be pictographic or ideographic)	Figure 4.14
8	The point of view between steps should not be changed	Figure 4.12
9	Although pictures may be metaphors, these should be displayed in a gravitationally stable manner	Figure 4.15
10	Parts within a group should be added to an assembly at the same time or in sequence with one after another	Figure 4.12
11	Represent hierarchy and abstraction within the instructions if there is an opportunity to do so	Figure 4.15
12	Select a view of the resultant output that maximises all features	Figure 4.13
13	If possible show all parts affected during the software execution, seen and unseen for contextualisation	

existing literature of PAIs. Gestalt theory specifically assists with the order of steps and the coupling of picture and code together.

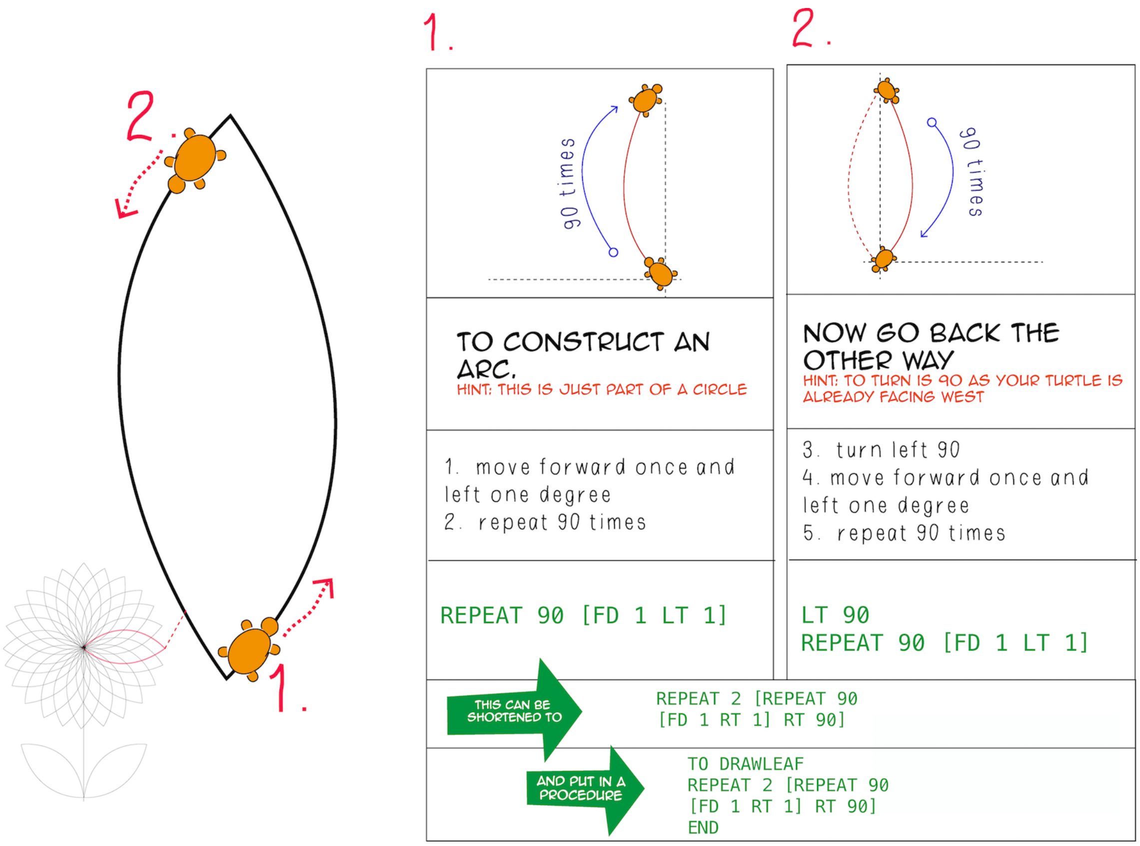

FIGURE 4.59: Arrow and code execution

Figure 4.60 is an attempt to represent a group of cars, showing how different types of cars are related through a hierarchy. Inheritance is a concept sometimes used in computer science where an object inherits the code of a parent object previously programmed. The existing code is built upon and added to and because of inheritance a programmer uses less code. The hierarchy in Figure 4.60 represents new code built upon existing code. Features added to the new objects require minimum lines of code.

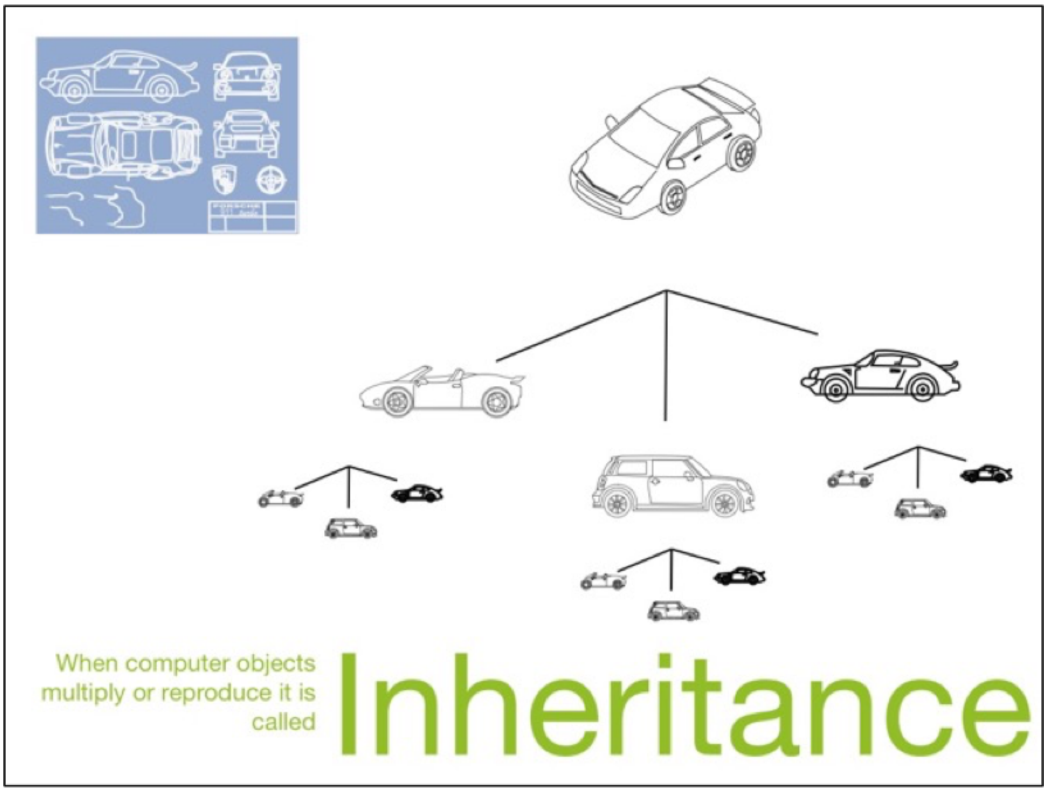

FIGURE 4.60: Inheritance concept

The discussion on pictures firstly examined PAI literature as well as information design. The PAI literature provided a way to navigate a complex technical topic such as programming and gave a tangible equivalent to build themes upon, for information design. The research into pictures within TOAOCP began in this way.

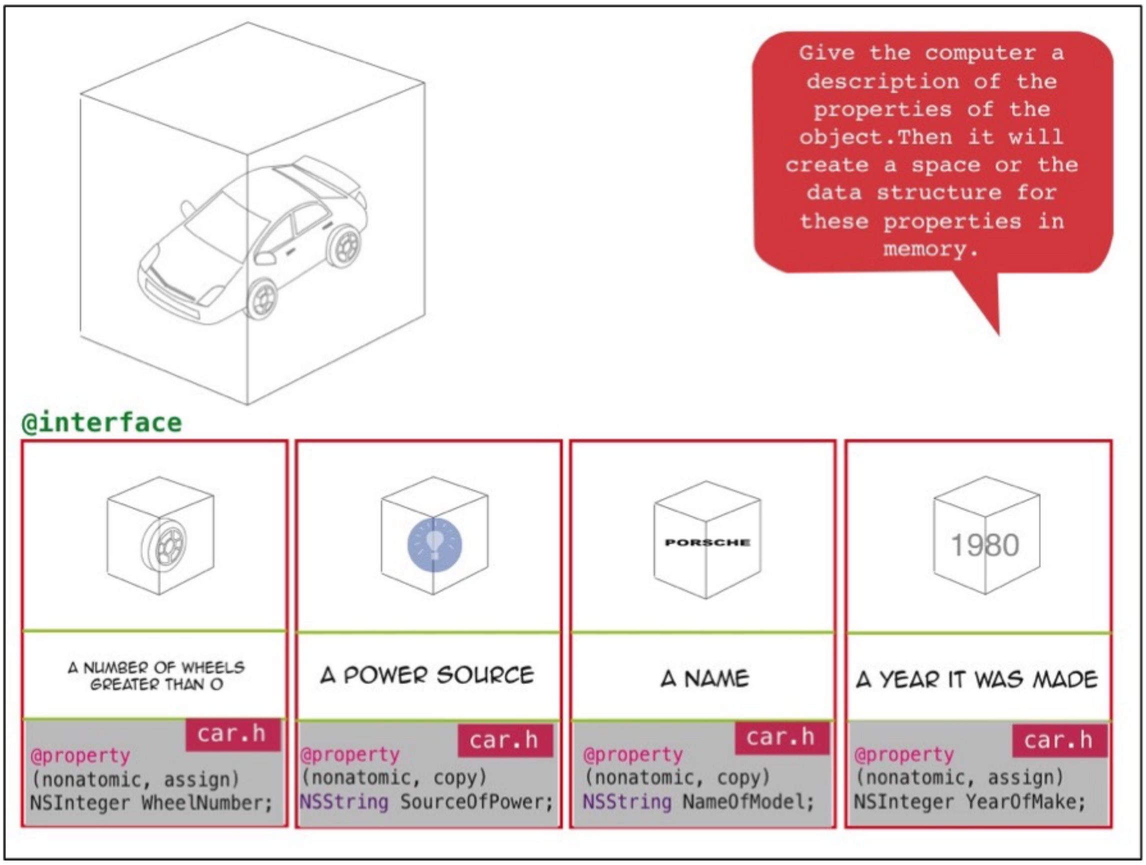

FIGURE 4.61: Representation of storage and code together

Coding within computers is not seen, as the nature of programming is principally invisible. Debugging is a method of asking the computer to show the programmer what it is executing. During the construction of the milestones for TOAOCP in Research Phase One, the inner workings of the machines were sketched and then drawn in steps. Figure 4.61 contains the data structure programmed along with the code. This programming segment is part of the interface of an iPhone application. During this thesis, I attempted to use the principles of PAIs to communicate programming. Where there was a sequenced order of steps within the programming code, a picture sequence was used. PAIs are based upon sequences of picture and text arrangements. By arranging the programming in picture sequences in TOAOCP (see Appendix A), key concepts within programming became clear to me. Before learning programming, it is useful for a student to grasp a core set of competencies that are grouped under computational thinking.

4.4.5 Computational thinking

Seymour Papert, a student of Piaget, defined computational thinking as being a process where a general solution is a sort of open-ended question. Computational thinking has its foundations within constructionism and is defined by the following characteristics:

- Analysing and logically organising data;

- Data modelling, abstractions and simulations;
- Formulating problems such that computation may assist;
- Identifying, testing, and implementing possible solutions;
- Automating solutions via algorithmic thinking and;
- Generalising and applying this process to other problems.
(Stephenson & Barr, 2011)

These characteristics were examined within Research Phase One in the creation of the learning materials and the role of pictures. As Papert notes on his childhood observations of watching gears work, a gear acted as a transitional object to connect the "body knowledge" or "sensorimotor schemata of a child" (Papert, 1980). This type of thinking demonstrates a clear, constructive method of thought for children. Different picture types will emerge as appropriate for each of the characteristics listed above.

TABLE 4.14: Skills and techniques of computational thinking

Techniques	**Description**
Decomposition	Breaking a task into parts and steps
Pattern Recognition	Predicting and modelling to test
Pattern Generalization and Abstraction	Making laws and principles that cause these occurrences or patterns
Algorithm Design	Developing steps to solve similar problems so you can repeat this

Janette Wing, head of the Computer Science Department at Carnegie Mellon University, asserts that computational thinking is a lifestyle and attitude that is universal (Wing, 2006). She further states that along with reading, writing and arithmetic, computational thinking should be a skill set added to every child's analytical ability. Some of Wing's statements on what computer science is align with Professor Paul Denning and even Alan Turing. For example, she asks the question of what can be done better than a human by a computer? The ideas I have found within Wing's writing also align with those concerning schematic and cognitive architecture, for example:

> Thinking like a computer scientist means more than being able to program a computer; it requires thinking at multiple levels of abstraction (Wing, 2006, p. 4).

It is important at this stage to define some of the characteristics of computational thinking that build upon the information presented in Table 4.14. The characteristics of note are abstraction, decomposition, pattern recognition and algorithms. In contrast to the Peircean or perceptual ideal of abstraction (see Section 4.3.5), abstraction and computational thinking concern the filtering out of parts of information that we do not need to concentrate on. The attention is only upon the information that concerns the problem's solution. Details about information are removed in computational abstraction by a software writer and judgement, another characteristic of computational thinking, is exercised. For example, if a programmer wanted to find the names of every person living in a specific suburb, they would make a record for the 'suburb' when they were writing the software. The person's hair colour would not be recorded as the data is not required.

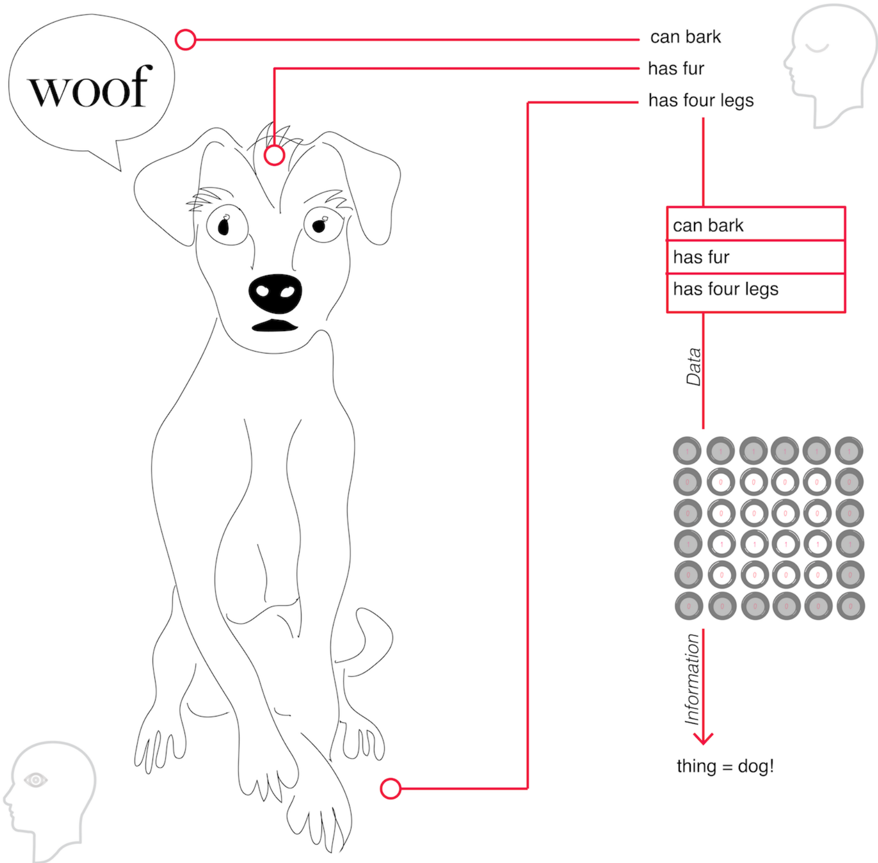

FIGURE 4.62: Dog characteristics and computation

Pattern recognition is also a characteristic of computational thinking. This characteristic acknowledges that certain things have elements in common. For example, a series of animals that have fur, a tail and which bark are considered to be dogs. The recurring pattern a software writer could use to identify a thing as a dog is as follows (see 4.62):

1. the thing has fur;
2. the thing has a tail;
3. the thing barks.

Decomposition is the breakdown of a complex problem or system into smaller parts. These smaller parts tend to be more manageable and easy to understand. By the process of decomposition, a problem is broken down into its constituent parts that are simpler to understand. For example, if a person wanted to find the constant speed a train was travelling at, they would need to know the distance covered and the time the train was travelling. Once the distance and time were known, then the velocity could be calculated as velocity equals distance over time. The problem is now a simple calculation that can be performed by a machine. Similarly, an algorithm specifies the order that the problem-solving steps occur. Algorithms can be expressed as a flowchart (see Figure 4.56).

Computational thinking combines a mix of identifying decompositional characteristics that can be measured (often referred to as data), ordering the steps that manipulate these characteristics, recognising and abstracting the characteristics or steps that are patterns and lastly, writing these characteristics and patterns into an order that makes an algorithm.

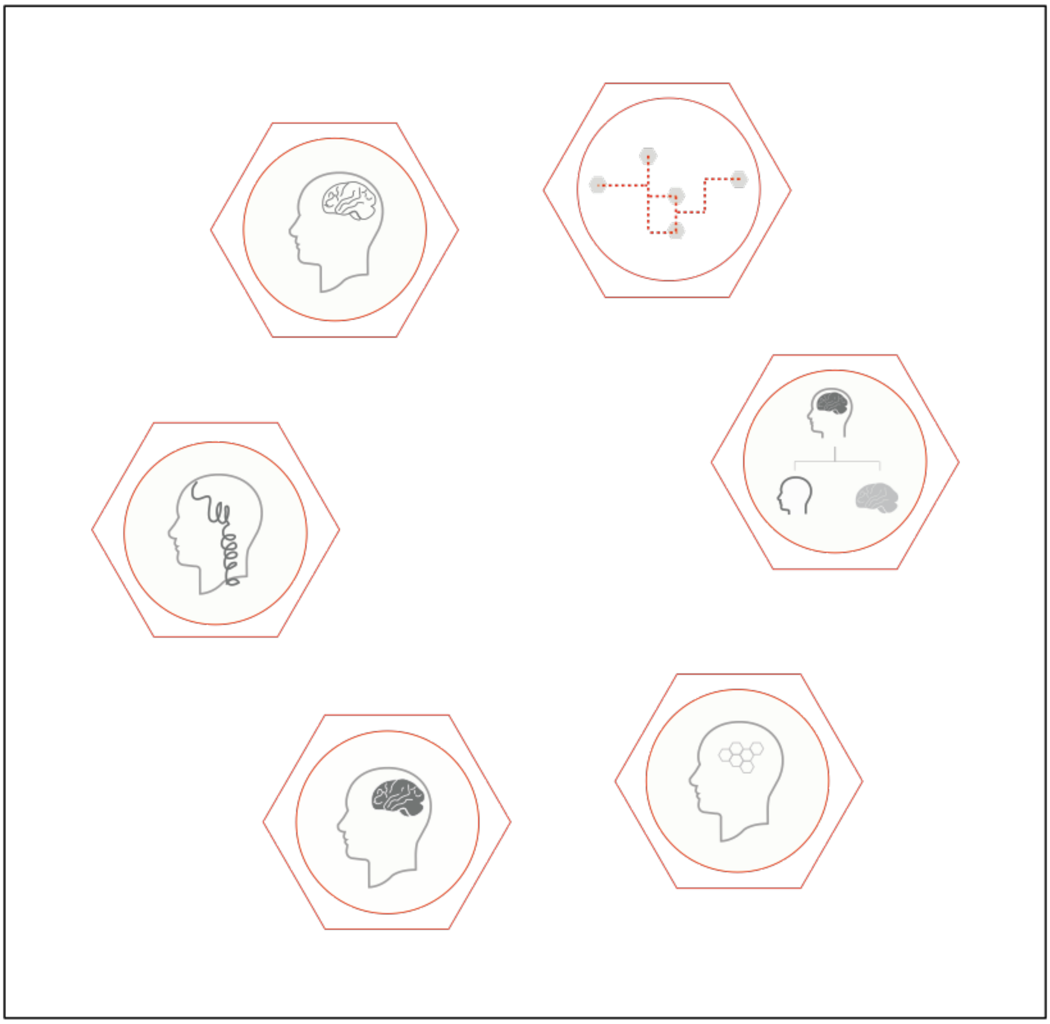

FIGURE 4.63: Computational thinking pictograms

The learning of computational thinking with the assistance of pictures is a core purpose of TOAOCP, and therefore pictograms were created to represent computational thinking (see Figure 4.63). Pictograms were sketched for any element that was going to repeat or be thematic within the milestones created for TOAOCP (see Appendix A). The reason for this was because these pictograms could be associated with meanings and were memorable. As the milestones created in Research Phase One were comics, there is also supporting evidence for using a pictorial device to access previous memories such as the zoetrope mentioned in Section 4.2.1. As Saraceni (2001) states "Readers of comics learn how to associate certain repetitive pictorial elements with specific meanings. . . " (p. 439). TOAOCP concerns the learning by aligning computation with comic book theory as comics are a design element that conveys sequence.

The computer programming section explored and explained a multitude of diagrams that are used in computer science and demonstrated that there is a lack of iconology and holistic representation. Within TOAOCP, patterns and structures were established and contextualised to computer programming to be used within education irrespective of the delivery medium. TOAOCP was also designed to measure the communication of the pictures to the viewer. Once the measures were taken, the research questions could be answered. The measures were the impacts.

The next section presents theories of adoption and gives examples of their application across a variety of disciplines. The impacts used to answer the research questions (see Section 3.1) are also addressed.

4.5 Measurement and theories of why people adopt a learning technology

The last section of the literature review explains the theoretical quantitative methods used in TOAOCP. The factors and constructs used within TOAOCP came from the following theories of adoption. The following three theories and model discussed are the expectancy-value (EV) theory, the theory of reasoned action (TRA), the theory of planned behaviour (TPB) and lastly the technology acceptance model (TAM). The origin of factors used in the pretest (t0), posttest (t1) and evaluation (t3), was modified for TOAOCP (see Appendix B). Firstly the reason why a technology acceptance model (TAM) was chosen to measure the acceptance of the pictures will be discussed.

Literature abounds on models that aim to explain the constructs influencing the adoption of innovations (Ramirez & Beilock, 2011; Hulleman & Harackiewicz, 2009). However, there is a gap in the existing literature regarding the examination of the impact of graphic design on the adoption of media or technology. Within TOAOCP, pictures and comics have both been classified as devices of design or communication and have been aligned with technology to predict the factor of intent to learn computer programming by a student. The theories named in the preceding paragraph are measures of communication. This section now continues with the historical development of the impacts measured in TOAOCP starting with a discussion on expectancy-value theory (EVT).

4.5.1 Historical development of the adoption theories

Professor John William Atkinson developed expectancy value theory (EVT) to understand how an individual is motivated. Two main areas form the basis for the theory of expectancy value theory (EVT). These are expectancies for success (E) and subjective task values (V). According to Iten and Petko (2016) the expectancies and values, engagement, interest and academic achievement of learners can all be predicted. Expectancies and values are salient drivers of motivation along with the beliefs and behaviours of an individual. Research Question Three has been included to assess the beliefs and values of the participants when learning computer programming when using pictures in sequence. Icek Ajzen's book, *Attitude, Intention, and Behavior: An Introduction to Theory and Research*, formalised EVT (Trautwein et al., 2012; Bong & Skaalvik, 2003; Simons et al., 2004; Eccles & Wigfield, 2002; Eccles, 1983). Intervention programs have used expectancy value theory (EVT) to alter the motivation of an individual so as to increase the expectancy and value of a topic (Fishbein & Ajzen, 1977). There are many examples of value-focused interventions in education where the curriculum has been formulated to connect with the students. In this way, a student with a low expectancy of a topic can increase their interest level (Blackwell et al., 2007; Hulleman et al., 2010). Expectancy value theory (EVT) has led developments in attitude research and was also used to develop other theories that have built upon it, such as the theory of reasoned action (TRA).

The theory of reasoned action (TRA) concerns persuasion and it is used to measure understanding within different communication styles or discourses. Developed in 1967 by Martin Fishbein and Icek Ajzen (Fishbein & Ajzen, 1977), the theory of reasoned action (TRA) came from examining different individuals' attitudes and behaviours and seeing what leads somebody to action. This theory predicts the actual behaviour of a person based on their prior attitudes and on how they intend to behave. Factors within the theory of reasoned action (TRA) include intention, which is a function of attitudes and subjective norms (see Figure 4.64).

Within this thesis, the theory of reasoned action (TRA) was contextualised to explain whether or not an adolescent would choose to use pictures to learn programming. The theory of reasoned action (TRA) is justification for further research within graphic design and learning. The role of graphic design within education and more specifically computer programming is relatively un-researched. Psychologist Fred Davis used the theory of reasoned action (TRA) to propose a technology acceptance model (TAM) in 1986. These persuasive models are often used to predict the utility of technology within an organisation. Figure 4.64 represents the relationship between the attitudes toward something and behavioural intent.

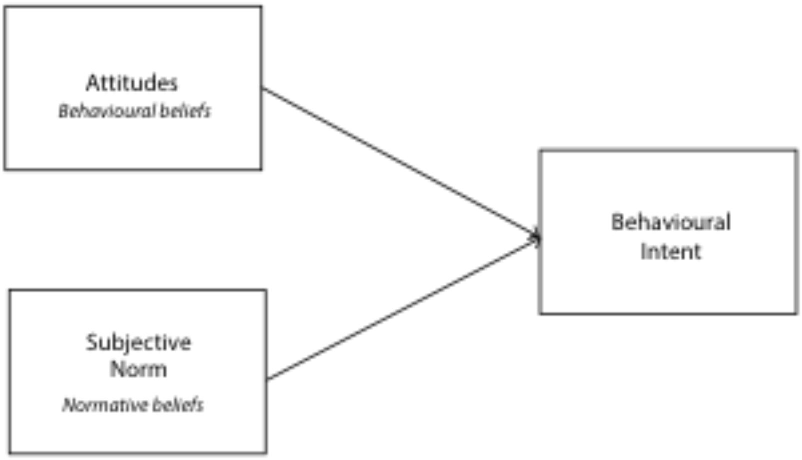

FIGURE 4.64: Theory of reasoned action

The affects of attitude from the TRA are examined within TOAOCP as they define the impacts in Research Question Three. The TRA was used to measure the picture data and comic data. The measure of the subjective norm (SN) (defined below) was excluded from the picture analysis. It was more important to ascertain the influences form family and friends about the use of comics upon the intent of an adolescent to learn programming than the influences of pictures. Research exists connecting comics as a novel instead of serious form of learning for children. There was not enough reason to examine the relationship between the SN and intent for the design element of pictures. However, because comics are not a traditionally used method of learning within education systems, I decided to measure the SN for the comic design element.

Attitudes
The discussion now moves to the data on the participants attitudes, which formed the basis for an initial answer to Research Question Three. An individual's beliefs and values are formed from their attitudes towards a given behaviour (Ajzen, 1991a). The definition of attitude within TOAOCP has been adopted from Icek Ajzen's and is as follows: a person's evaluation of their need for the intended behaviour (Ajzen, 1991b). Attitude is further discussed in Section 5.5.1. A combination of five factors make up the the participant's attitudes. These five factors are usefulness, simplicity, fun and enjoyment, personal ability and fear. These factors are derived from the theory of planned behaviour and are discussed later within this chapter (see Section 4.5.2). Attitudes are one of two factors within TOAOCP that predict the intent to use an artefact. By combining attitude and the subjective norm, the actual behaviour comes from an individual's intent to use an artefact. Figure 4.65 depicts the relationship between actual behaviour and intent.

Subjective norm (SN)
According to Ajzen (1991b), the subjective norm (SN) is "...the perceived social pressure to perform or not to perform the behaviour..." (p. 188). It is a normative belief about

the extent to which other people who are relevant to an individual think or do not think that they should perform a particular behaviour. SN was included in the measurements for comic data because of evidence found while researching the literature review from some sources on social perception toward comics. There were claims of a social stigma attached to comics (Caldwell, 2012; Aleixo & Norris, 2010; Botzakis, 2011) as well as a negative response to the use of comics as a tool to be applied in an education setting (Fischbach, 2014).

Behavioural intent

Behavioural intention (Intent) is a person's likelihood that they will engage in a given behaviour. Actual use is a variable that is not represented in Figure 4.64 although it naturally follows that actual action follows from intention. Ajzen extended his original communication model of the theory of reasoned action (TRA) as he found that perceived behavioural control (PBC) impacted upon actual use (see Figure 4.65).

4.5.2 Theory of planned behaviour (TPB)

The theory of planned behaviour (TPB) links beliefs and behaviour in the same way that the TRA does and is an extension to TRA by Icek Ajzen (Ajzen, 2005). The difference between TRA and TPB is the new factor of perceived behavioural control (PBC) (see Figure 4.65).

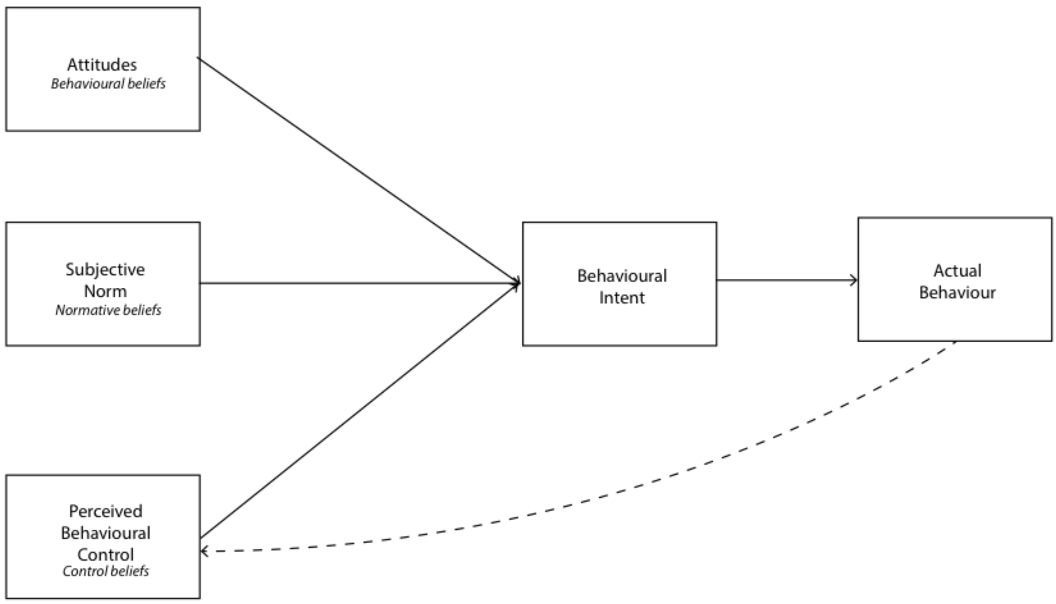

FIGURE 4.65: Theory of planned behaviour

The perceived behavioural control (PBC) was introduced to refer to the degree that a person thinks they control a given behaviour. Section 6.1.8 discusses perceived behavioural control (PBC), which is a two-factor construct. If a person has high perceived behavioural control (PBC), they are more confident and will therefore be more capable of performing the intended behaviour. The two constructs that perceived behavioural control (PBC) measures are self-efficacy and controllability. Self-efficacy is the level of difficulty experienced when performing the behaviour, which is also dependant on an individual's belief in their ability to succeed.

Controllability contains outside factors that are uncontrollable by the individual, for example, a person can fill out a digital survey "if' they have access to the Internet. The presence of the Internet would represent controllability by the individual. These two constructs represent PBC. Within TOAOCP only self-efficacy was measured. The single for the single measure for PBC was based on the user test being a paper prototype as there was a high expectation that the participants would know how to fill out the instrumentation and there was no digital user interface involved.

4.5.3 Technology acceptance models (TAMs)

The discussion continues with the model used for TOAOCP. The technology acceptance model (TAM) was derived from a theory from Ajzen and Fishbein's TRA, which is widely accepted and influential. The technology acceptance model (TAM) was derived from an information systems theory that models a user's acceptance and use of a new technology and the theory of planned behaviour. According to Davis (1989), there are two factors that influence an individual's decision about how and when a system will work. These factors are:

- Perceived usefulness (PU)
- Perceived ease of use (PEOU)

The TRA's attitude measures are measures of 'usefulness' and 'ease of use'. Table 6.5 in Chapter 6 lists the measures of attitude with some factors in TOAOCP.

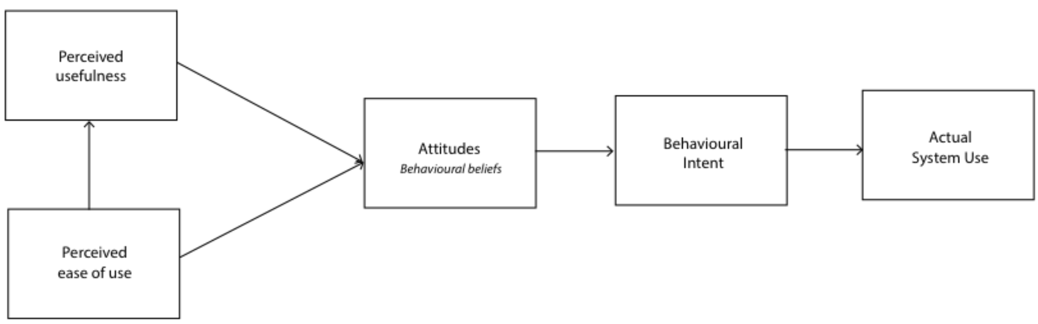

FIGURE 4.66: Technology acceptance model

As discussed previously in this chapter (see Section 4.5.1) the attitude factor within the technology acceptance model (TAM) was further broken down into five factors that were measured through the data collected in Research Phase Two. Behavioural intent has been discussed previously in Section 4.5.1. The attitude factors in the technology acceptance model (TAM) model were:

- Usefulness;
- Fear;
- Fun and enjoyment;
- Simplicity; and
- Personal ability.

This study adapted an existing technology acceptance model that was developed by Nina Iten and Dominik Petko (Iten & Petko, 2016). The validity of the data was calculated by factor analysis for the pilot study (see Section 5.7) in Research Phase One and Research Phase Two in Chapter 5 (see Section 5.3). The purpose of the technology acceptance model (TAM) is to determine the effects that are most influential to the intent to learn computer programming. The original technology acceptance model (TAM) model was slightly modified to fit a graphic design context (see Appendix B). All factors were identical to the original technology acceptance model (TAM). What follows is a discussion of each factor from the technology acceptance model (TAM) model starting with usefulness. The adaption of the factors is listed in Section 6.1.8 and Section 6.1.8 lists the adaption of the factors as well as in Appendix B.

Usefulness
Usefulness within TOAOCP follows the definition of perceived usefulness and is defined as the degree to which a person believes that their job performance will be enhanced by using a particular piece of technology (Davis, 1989). For my research, usefulness, therefore, refers to how much the learner believes the pictures will help improve their learning. A user of the pictures and learning comic proposed in TOAOCP would feel that the devices are capable of being used advantageously. Usefulness has been found to be an influencing factor towards acceptance within advertising to adolescents, mobile financial applications, brand attachment, tourism and health games (Martí Parreño et al., 2013; Amoroso & Chen, 2017; Yang, 2016; Beier & Aebli, 2016). Within e-learning, usefulness and cognition have been found to be significantly related (Snchez-Prieto et al., 2017). Pictures have been documented as cognitive tools or devices of thought (see Section 4.2.4). A learner should recognise the use of pictures during tuition as useful. This factor emerged as a dominant factor in the results, that is usefulness proved to be a strong predictor when using pictures to learn to program (see Section 6.1.3 in Chapter 6).

Simplicity
Simplicity has been examined as a factor within technology acceptance models (TAMs)

when learning management systems (LMS) are evaluated (Goh et al., 2013; Šumak et al., 2011); this can be within educational multimedia (Gao, 2005) as well as within social media tools for retail (Lorenzo-Romero et al., 2014). Simplicity is a measure that contributes to the perceived ease of use of a system. For my research simplicity defines how effortless the communication of the pictures are to the participants. It is interesting to note that within the Wilcoxon Signed Rank test (paired T-test) testing, pictures were not as simple to interpret as the participants initially believed they would be (see Section 6.3.12).

Fun and enjoyment
TOAOCP does take fun into account as a predicting factor of innovation adoption. Fun and enjoyment within TOAOCP is the extent to which viewing the pictures are fun, aside from any learning consequences that result from using the pictures to learn through. Davis et al. (1992) first defined perceived enjoyment of an activity and its impact upon use. Many studies have considered fun within a technology acceptance model (TAM), particularly when concerning children and learning (Iten & Petko, 2016). Previous studies have considered fun to embrace a more hedonistic meaning rather than just utilitarian motivations that simply encourage learning (Saber Chtourou & Souiden, 2010; Van der Heijden, 2004; Leng et al., 2011). Within the instrumentation (see Appendix A), the inclusion of pictures initially had an influence in making learning fun (see Section 6.1.3). Fun and enjoyment within the technology acceptance model (TAM) was a salient measure in TOAOCP.

Personal ability
Personal ability to succeed in a situation is related back to self-efficacy and self-belief. According to Bandura:

> Self-efficacy is a context- related judgment of personal ability to organize and execute a course of action to attain designated levels of performance; whereas self-concept is a more general self-assessment that includes other self-reactions. (Zimmerman, 1995)

Individuals have a prior belief of their personal ability to achieve objectives in learning and this perception impacts the individual's behaviour. Personal ability was included in TOAOCP as a factor to check if this had any impact on motivation, which it did (see Section 6.1.8). Figure 4.67 is a diagram representing the relationships concerning these factors.

Fear
Fear within TOAOCP refers to concerns that might arise in using pictures and comics when learning. Any anxiety about understanding visual communcation may be significant from the data collected by this factor. The three items within the factor of Fear were each measured for pictures and comics. The questions concerning the fear were modified from questions about computer anxiety as this tends to increase negative attitudes in learners and deters an individual's personal development (Durodolu, 2016; Dupin-Bryant, 2002).

Anxiety is often present when knowledge is acquired (Durodolu, 2016). Cognition is affected by anxiety when an individual cannot adapt to change (Dupin-Bryant, 2002) and therefore learning performance is impaired (Verkijika & De Wet, 2015). The issues concerning the interpretation and meaning of visual communication occurred in general in the focus groups (see Section 6.3.5 in Chapter 6). The impacts upon the factor of Fear are discussed further in Section 4.5.3 and Section 6.3.9 in Chapter 6. Section 6.3.9 in Chapter 6 discusses fear of assessment.

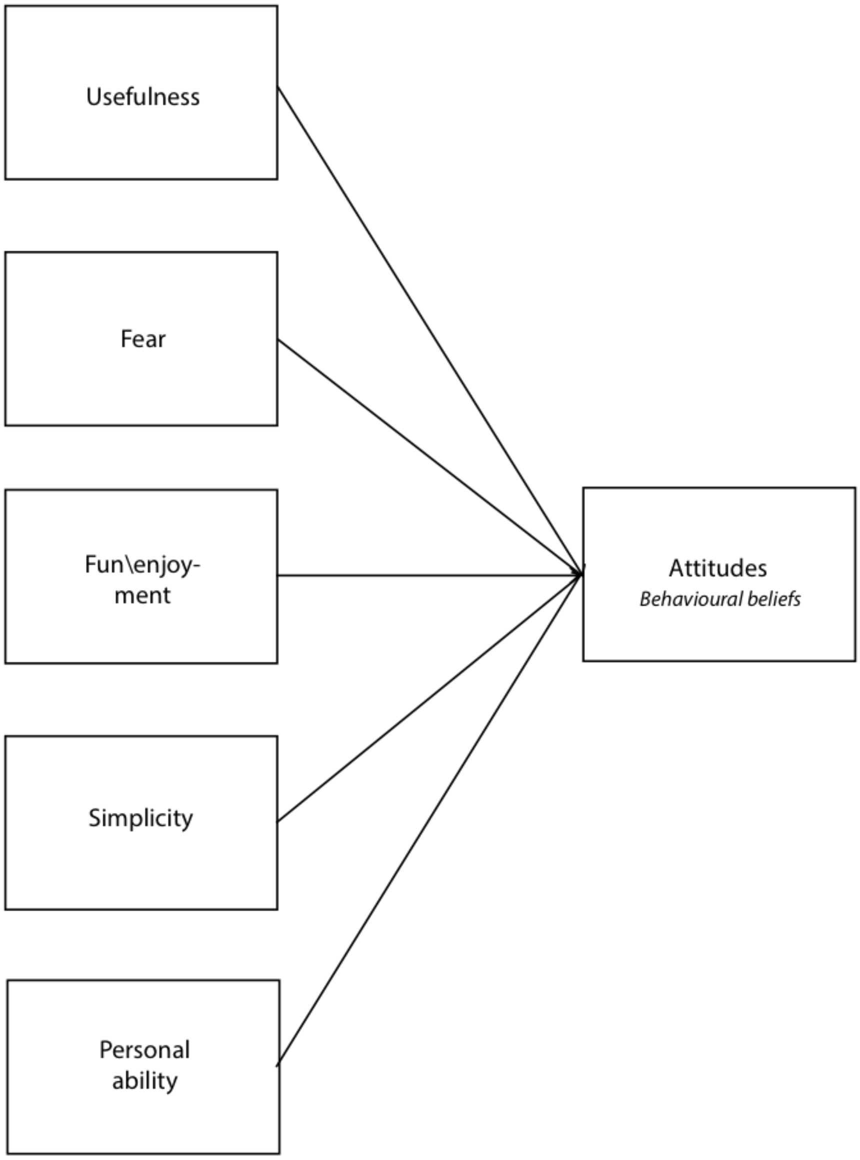

FIGURE 4.67: Factors that determine attitude

As the instrumentation for TOAOCP was a paper prototype (see Appendix A), any interactive features like interactive help or feedback from using a digital device were not included as factors that might have an impact on attitudes. Factors that involved the evaluation of the instrumentation (see Appendix A) by the participants are called the evaluation items.

4.5.4 Evaluation of the learning comic

Further questionnaire items were developed to evaluate the learning comic. The extra questions were necessary to understand the effects of the learning comic on the research themes of motivation and cognition.

Perceived behavioural control
As an added measure within the evaluation items in the questionnaire perceived behavioural (PBC) control could also be calculated. Although the following statements seem contextualised toward digital devices, I made a decision to leave the terminology as close to the original study (Iten & Petko, 2016) as possible in order to have pictures and comics considered as devices of perception and tools of thought in their own context. These items in the questionnaire were:

- "Using this type of comic is entirely within my control."
- "I have the knowledge and ability to use these type of comics."
- "I am able to skilfully use this type of comic. "

These items are a measure of one of the two sub-constructs that make up perceived behavioural control (PBC). PBC was added to deal with "... situations in which people may lack complete volitional control over the behaviour of interest" (Ogbonna, 1993, p. 42). Figure 4.68 displays the interaneous and extraneous processing measures that form PBC.

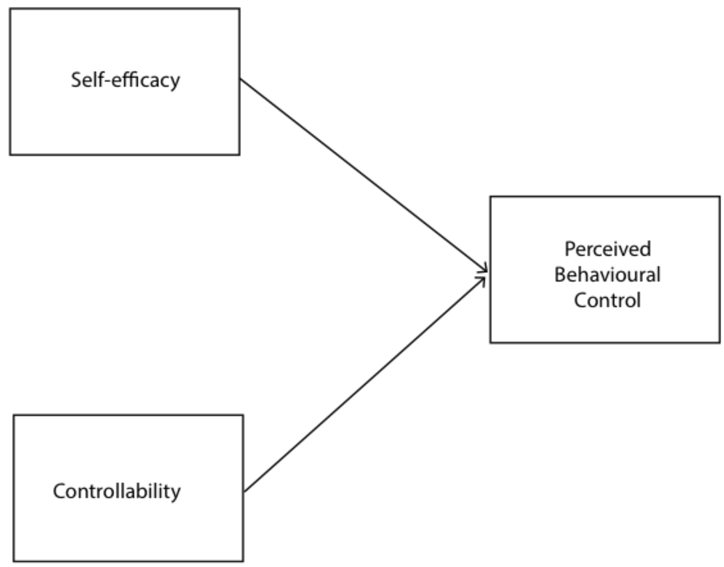

FIGURE 4.68: Perceived behavioural control and sub-constructs

According to (Ajzen, 2002), the sub-constructs are self-efficacy, meaning one's perceived ability to perform each step, and actual controllability, where this is actually outside of the learner's control. Here self-efficacy is internal while controllability is external. An example of controllability is having access to an online resource, such as possessing a login and password, while an example of internal control could be how well a person can use the mouse when accessing online materials. Understanding visual communication would provide a core advantage when applied to a learning comic as PBC would then score quite highly.

The first two principle themes of learning in TOAOCP were cognition and motivation. The measure of attitude towards learning was a summative variable of the five factors (see Figure 4.67). These three measures of self-assessed cognition and self-assessed motivation and attitude respectively address the Research Questions One, Two and Three.

All factors in the original evaluation section of the study (Iten & Petko, 2014) were retained except for two because these would not work with the prototype. These factors were 'interactive help' and 'online help' and they were not applicable to the participants. The subjective norm (SN) measure was also excluded from the picture items as discussed previously (see Section 4.5.1). The instrumentation was modified to fit the non-interactive nature of the comic. Self-assessed cognition and self-assessed motivation were the measures used for the degree of effect of Research Questions One and Two. These two research measures of self-assessed cognition and self-assessed motivation are outlined in the following sections, along with the instrumentation designed to model all three factors of self-assessed cognition and self-assessed motivation and attitude.

Cognition in TOAOCP

Three types of cognition were measured within TOAOCP. These were actual cognition (t1) measured by the test scores or knowledge test, self-assessed cognition (t3) arrived at by collecting data from three items, and lastly perceived cognition that measured how well the participants believed they understood the pictures and comic. Self-assessed cognition was the participant's belief of their own understanding of the pictures and/or comic. Participants recorded the data during the viewing and reading of the comic. The data from the test scores was named the actual cognitive test (t1). The variables gathered from this process are labelled as test scores in the results section (see Chapter 6, Section 6.2). The knowledge test was included in the study to see how effective the learning comic was. From the initial results, it was evident that the majority of children understood the comic, and additionally that they had learned something about computer programming from it (see Chapter 6, Section 6.2).

The second type of cognition looked at in TOAOCP was self-assessed cognition, Section 7 discusses this complexity of measuring this type of cognition as well as what it may suggest. Self-assessed cognition was measured as a summary of the following three items (see Table 4.15):

- "In the lesson I learnt about programming."
- "In the lesson I learnt I should avoid programming."
- "Because of this lesson I am more confident about programming."

Data for the above three items were gathered without the participants knowing their test scores. These test scores were not individually given back to the participants because of the anonymity of TOAOCP and time restraints. A future direction for the research in TOAOCP would be to return the test scores to the individual participants and measure the impacts upon their confidence levels. Then the impacts upon confidence could also be included and measured in the study. The results for self-assessed cognition are discussed in detail in Sections 6.1.5 and 6.1.5 and, more specifically, the links to fun and learning through pictures, are also discussed.

Social cognitive theory is used in TOAOCP to explain hypothesis seven (H7p) listed in Section 5.2 for pictures. H7p concerns the idea that an individual's personal ability about computer programming increases as they believe that they understand the pictures better. The part of social cognitive theory (SCT) that applies to this hypothesis is psychologist Albert Bandura's perspective. Bandura's perspective concerns obervations, imitation and modelling integrated with interaction between behaviour, factors such as cognition and the environment. His model of social cognitive theory (SCT) is based upon reciprocal causation. Self-efficacy is an individual's confidence in their own ability to achieve the results that they want or intend (Ormrod, 2006). Personal ability measures self-efficacy in TOAOCP. Bandura claimed that social learning theory (SLT) shows a correlation between a person's perceived self-efficacy and their behavioural change (Bandura, 1985). SLT is a popular theory to apply to the context of learning, motivation and goal achievement. In

2001 the approach was updated for mass communication and symbolic communication (Bandura, 2001). Bandura's theory focuses on equality of the individual.

Motivation in TOAOCP

The literature review now discusses motivation followed by the attitudes that are measured within TAOOCP. Motivation was self-assessed by the participants and measured in the research so as to examine the impact that all factors might have upon it. The motivation model for pictures was designed to answer Research Question Two. Motivation in TOAOCP was considered in an instructional context, in this case provided by the learning comic. Like much research into learning, the tasks are goal-directed, that is, the learning is undertaken to achieve an aim. The purpose of the learning comic was to educate the participants on computer programming. Although the participants were informed that they were not being evaluated and their teacher would not get a copy of their marks, the learning was nevertheless goal-directed. The participants had many questions and the lesson seemed to impact on their motivation positively. Section 7.2 is a summary of the impacts upon the participants motivation.

Pintrich and Schunk (2002) in their book *Motivation in education: Theory, research and applications*, define motivation as "the process whereby goal-directed activity is instigated and sustained" (Anderman & Dawson, 2011, p. 219). Motivation in this study is also intrinsic or "... the performance of an activity for no apparent reason other than the process of performing it" (Moon & Young-Gul, 2000, p.218). Furthermore, motivation is also a combination of social as well as cognitive factors. By the views of these accepted theorists, the factors that measured self-assessed cognition and self-assessed motivation were related in TOAOCP (see Section 7). The use of pictures and visual communication to learn programming was evaluated in relation to; self-assessed motivation, self-assessed cognition and finally to behavioural attitudes. As there exist different influences on motivation, it was self-assessed by the participants.

The discussion now moves on to other factors that were included in the quantitative study.

Clarity The measure of clarity (see Table 5.4) was included to see how much thought participants put into recognising the individual pictures. Clarity describes the participants visual reactions to the pictures and also if the pictures were interesting to them as a learning or didactic experience.

Strategy

Strategy was a measure used for the combined affects of the pictures in sequence. As the Z-path is the way that the eyes track across a page in reading, strategy evaluated learning through pictures with a non-linguistic narrative. The measure of strategy (see Table 5.4) evaluated the pictures in sequence as opposed to the measure of clarity that concerned recognisability of the images.

Flow

The flow measure was included to explore the participant's level of flow when learning

TABLE 4.15: Summary of cognition and motivation types

Theme	Measure	Sources
Actual cognitive test Tested learning gains t(1) – Six questions	Test scores from the knowledge test	Myself
Self-assessed cognition	"In the lesson I learnt about programming."	Iten and Petko, 2014
t(3) - Three items	"In the lesson I learnt I should avoid programming."	
	"Because of this lesson I am more confident about programming."	
Self-assessed motivation	"The lesson increased my interest in programming."	Iten and Petko, 2014
t(3) - Three items	"Whilst in the lesson I would like to learn more about programming."	Anderman and Dawson, 2011
	"Because of the lesson, I am more aware of programming concepts."	

through pictures placed within a specific order. In-depth reasons of why flow was measured were addressed in Section 4.3.6. The results of flow are covered in Section 6.1.5 and Section 6.1.5.

Other evaluation measures tested in studies
The above measures were those that had a significant impact somehow within TOAOCP and therefore were used to answer the research questions. Other measures investigated included confidence, picture literacy and picture representation. These measures were adapted from a questionnaire concerning the evaluation of learning and enjoyment within an interactive gaming environment (Fu et al., 2009a) and are listed in Table 5.4 in Chapter 5. This brings the discussion introducing the impacts to a close. A summary of the impacts can be seen in the following Table 4.16.

4.5.5 Retrospective research design - establishing hypotheses after the fact

Retrospective analysis is essential for some research studies. The *Encyclopaedia of Research Design* states:

> A retrospective study design allows the investigator to formulate hypotheses about possible associations between an outcome and an exposure and to

TABLE 4.16: Impact factor summary

Impact factor	**Factor**	**Theory**
Usefulness	Attitude	Theory of planned behaviour
Simplicity	Attitude	Theory of planned behaviour
Fun and enjoyment	Attitude	Theory of planned behaviour
Personal ability	Attitude	Theory of planned behaviour
Fear	Attitude	Theory of planned behaviour
Subjective norm	-	Theory of planned behaviour
Intent	-	Theory of planned behaviour
Perceived behavioural control	-	Theory of planned behaviour
Cognition	Self-assessed and actual	-
Motivation	Self-assessed	-
Clarity	E-Game Flow	E-Game Flow Questionnaire
Strategy	E-Game Flow	E-Game Flow Questionnaire
Picture literacy	E-Game Flow	E-Game Flow Questionnaire
Picture representation	E-Game Flow	E-Game Flow Questionnaire
Flow	Flow	E-Game Flow Questionnaire

> further investigate the potential relationships" (Salkind, 2010), and furthermore they are used " ... for obtaining preliminary measures of association." (Salkind, 2010).

More specifically a retrospective cohort study allows a researcher to " ... obtain preliminary measures of association for the development of future studies and interventions" (Salkind, 2010, p. 1284). According to Hess (2004), assistant director of respiratory care at Massachusetts General Hospital:

> A particularly useful application of a retrospective study is for a pilot study completed in anticipation of a prospective study. The retrospective study can help to focus the study question, clarify the hypothesis, determine an appropriate sample size, and identify feasibility issues for a prospective study (p. 1171).

Gearing et al. (2006) further states the following concerning retrospective research:

> Retrospective research has become largely undervalued and underutilized in child and adolescent psychiatry with the increasing singular focus on randomized control trials, despite the wealth of clinically relevant data available in historical medical records (p.126).

Retrospective quantitative study designs have been used successfully in medical studies to predict postoperative pain (Hauglum, 2015); to determine differences in neonatal intensive care units with different architectural layouts (Joshi et al., 2018); to investigate associations of the drug Remifentanil and heart rate patterns in neonatal outcomes (Boterenbrood et al., 2018) and also to analyse chronic liver disease (Oey et al., 2018).

Maymin and Gutmann (1992) took the retrospective analysis a step further by testing retrospectively developed hypotheses. Retrospective hypotheses were used in the research because in many situations people form the hypothesis "... after looking at the data" (p. 335). By analysing the data through I was able to find some significant patterns indicating the impacts upon the participants using pictures to learn to program through. The retrospective establishment of the hypotheses was used in TOAOCP to examine the impacts and answer the research questions.

The measurements used for the quantitative component of the research have been discussed within this chapter (see Section 4.5). The literature review concludes with a summary. An analysis of the research methodology is covered in Chapter 5.

4.6 Conclusion to the literature review

In conclusion, the literature review positions the role of the image within a framework for teaching complex learning. Pictures and visual communication are often seen as an addendum to linguistic materials in the discipline of learning. Linguistics seem to dominate, despite the introduction of technologies such as the graphical user interface, which is perfect for the display of a wide range of visual representations.

To understand the purpose of the study, that is, how pictures and visual communication can impact upon the learning of computer programming, a wide theoretical investigation has occurred. Table 4.17 highlights the major points within the literature review.

TABLE 4.17: Conclusion to the literature review

Graphic Design
• Non-realistic schema presents image aspects that enhance understanding in spite of being non-representative of real life. • The third type of vision is that which can be seen as existing in a person's mind, but is yet to be invented or proven. The pictures created for TOAOCP represented programming concepts that cannot be seen. • Pictures occur in sequence and represent the order of information in a comic. • Comics are a popular choice for narrative and TOAOCP measured the impacts of using a comic to learn computer programming. • Different levels of visual realism are presented in pictures to mean different things. Visual realism can range from photorealistic through to line drawings with little interior detail, through stick figures, down to ideogrammatic symbols whose meaning must be agreed upon for useful communication to occur. • Guidelines exist from visual theorists and Universal Design theorists on how to place pictures within the context of learning. • Information designers promote a blending of the modes of visual communication to produce information.
Learning
• Motivation and cognition are themes that affect learning. The evaluation items (t3) measure the two factors. • A technology acceptance model (TAM) assesses a student's intention to use new technology using a 'pretest' (t0) and a 'posttest' (t3). • Pictures are the oldest form of technology that we learn through and possess a meaning that is perceived differently to linguistics. • The ability to learn through pictures is assisted by using the features of visual rhetoric: logos (logic), ethos (ethics) and pathos (emotion). These characteristics should have a higher priority in the production of graphically designed learning materials than aesthetics. • When designing universal materials for learning, recognition, strategy and affective networks should be incorporated where possible. • The rapid adoption of new technologies into traditional learning areas has been accompanied by a decline in graphicacy within these learning areas. • Pictures can assist in solving problems and can also be used to represent computational thinking. • Forms of thought are supported through the appropriate design of pictures. Visual perception is an early part of the learning process that can be enhanced through visual communication. • Emotional design models can be used to enhance the learning process. • Cross-modal convergence can stimulate the learning process. • There is a range of picture types and design elements that are suited to different ways of learning. All are cognitive tools of thought. A range of picture types are adopted in the construction of the instrument.

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Computer Programming

- The use of metaphors with reference to things in the real world is not predominant in the learning of computer science.
- Computer science pictures lack iconicity and are highly contextualised. Diagrams that are context dependent, such as flowcharts, do exist within computer science. The original flowcharts of Alan Turing resembled a horizontal sequence like a Z-path.
- Computer science contains patterns of information, abstraction and computation. According to Piagetian theory on formal abstract operations, computational thinking is suited to a Year 8 student.
- There is a challenge with representing objects and processes that are non-Euclidean.
- Currently, programming is included within the digital literacy curriculum of Australian high schools but is not evident across all subjects. For example, a graphical information system (GIS) application could be written by the students in their geography class to show them how latitude and longitude coordinates work with a stream or data feed of information. Similarly, a graphic novel could be programmed by the students within English literature. By using pictures to describe the computer programming, a wider range of students can be taught to program than just those who understand mathematics. Teachers can teach programming in a wide range of subjects through using pictures.
- The knowledge within computer science should be accessed by a wide range of disciplines and applied to their respective subject disciplines. The application of programming to a wide range of disciplines within education would help to explain what can and cannot be programmed. In addition to this application of programming, the curriculums explaining this programming could educate adolescents in representing complexity through pictures and graphic design.
- A taxonomy of visual exemplars may be one way of accomplishing the preceding point.
- Computational thinking occurs throughout daily existence and is represented pictorially in this project as part of this thesis.

This literature review has examined learning through the conceptual lens of visual communication. TOAOCP uses visual communication as an unconventional way to stimulate the brain during learning. The specific topics discussed in the review were graphic design, computer science, learning and theories of adoption. Chapter 5 on the hybrid methodology will explain reasons for the selection of these topics, as well as specific details on the collection of methods used within the study.

Chapter 5

Methodology

The research purpose of this study was to investigate the effect that visual communication can have when used to teach computer science to adolescents. The overarching methodology is pragmatic research, which is a hybrid of mixed methods approaches that are flexible regarding technique, and collaboration with the stakeholders involved in the research.

Onwuegbuzie and Leech (2005) regard the pragmatic researcher to be holistic in approach, having prolonged engagement with the participants as well as making use of triangulation within the research design. For TOAOCP the commitment to the participants involved a twelve month engagement, while the relationship with the stakeholders was ongoing.

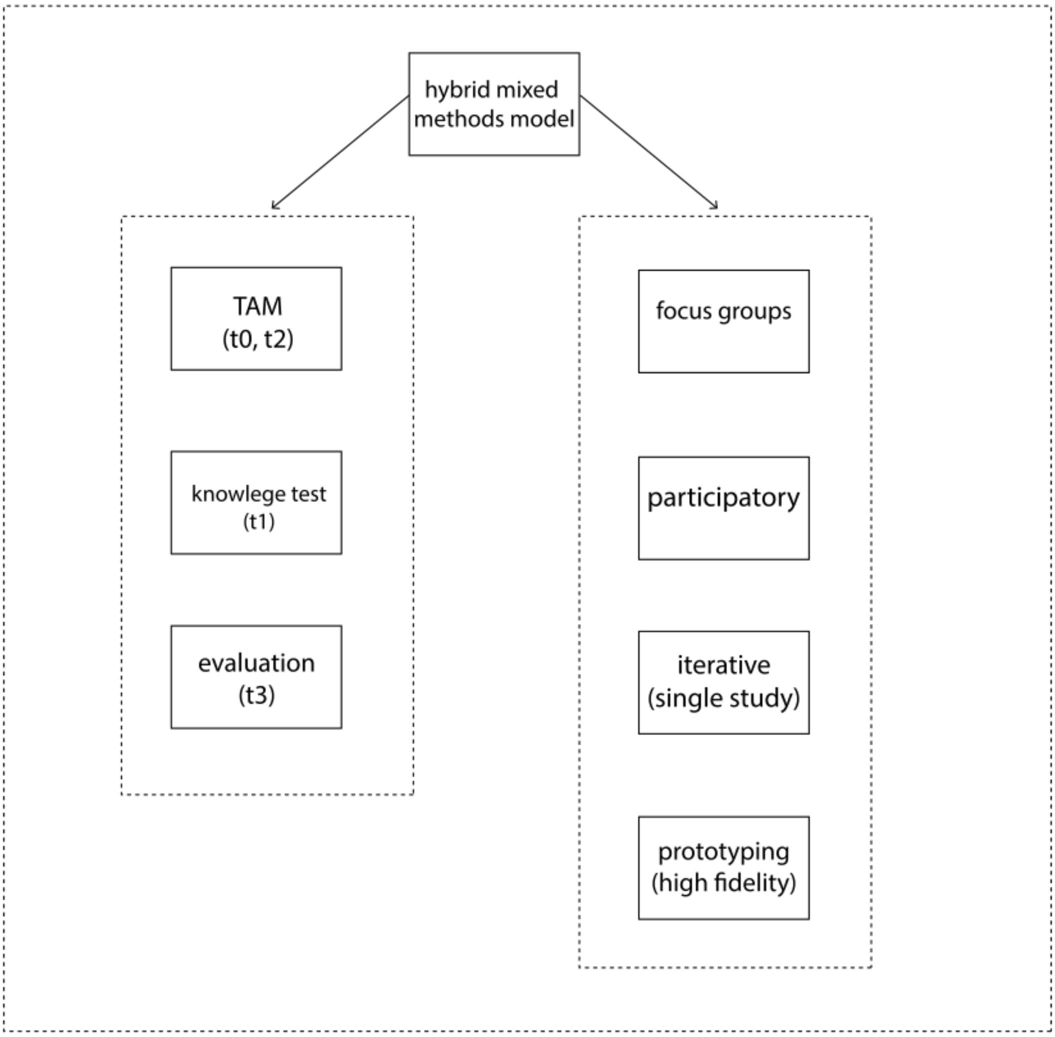

FIGURE 5.1: Methodology synthesis

An overview of this hybrid methodology can be seen in Figure 5.1. In addition to this a creative process (see Section 5.10) was also undertaken. Here the methods that are part of this hybrid model inform the creation of the prototypes. The creative process is discussed in detail in Section 5.10.

Both quantitative and qualitative methods of data collection allowed for the comparison of numerical data from the instrumentation, as well as providing further support from the qualitative data collected in the focus group discussions. Both types of data, quantitative and qualitative, were triangulated and summarised in the results section of the study (see Section 7). The methodology for this research was designed to collect data from the following:

- Participants' understanding (self-assessed and actual cognition) when learning through pictures and utilising visual communication;

- Participants' motivation for learning computer science;
- Participants' beliefs and values about learning computer programming through visual communication.

The data collection that involved the attendance of participants and some stakeholders was coordinated during Phase Two of the research plan. Research in TOAOCP prioritised the opinion of the users and involved collaboration from all of the stakeholders in the research process. In this way, the participants were viewed as having an influence and contributing to the design of the prototypes (Cross, 1982, 2006; Department, 2015; Kemmis & McTaggart, 2005).

The methodology now continues with a discussion of the research plan which describes the activities that were completed with both the participants and the stakeholders within a time frame. Additionally a detailed timeline of when this occurred is given at Table 5.3.

5.1 Research design

TOAOCP examines whether attitude and behaviour towards computer programming can be changed through visual communication. Year 8 student perceptions and the impacts of visual communication were examined through a survey that was administered from July 2016 to November 2016 as well as through two focus group discussions.

The research design therefore is a hybrid mixed methods one in that it contains a group of design methods (see Figure 5.2). There was a synthesis of iterative and participatory approaches here. The retrospective quantitative study design as mentioned within the literature review (see Chapter 4, Section 4.5.5), was conducted to expose the impacts when learning computer programming through visual communication. The retrospective hypotheses are discussed in full in Section 5.2. The conceptual framework in Section 5.2 incorporates the theoretical parts of the literature review and situates the research within the disciplines of graphic design, computer programming, cognition and technology acceptance.

A series of six, 40-minute lessons were also designed that incorporate visual communication and computational thinking (milestones - see Appendix A). The milestones were constructed to inform the creative component of the PhD. Along with this process of construction, notes and observations were also recorded in this thesis as part of the creative component. These lessons can also serve as paper prototypes and exemplars for information design that communicate to the participants. I used the data recorded on the instrumentation by the participants in the quantitative analysis.

The hybrid research design for this project was constructed to obtain data through the three research questions (see Chapter 3, Section 3.1). The data was also used to predict adolescent intent to learn programming through visual communication. The design consisted of three distinct phases: coordination, process and delivery. I first coordinated the stakeholders, delivered the instrumentation, collected the data and finally analysed the data. The rationale for this approach is that the quantitative data and its analysis will indicate the research problem as well as form an exploration into any relationships between the impacts (see Table 4.16). The impacts were listed and discussed in detail in Chapter 4 from Section 4.5.1 to Section 4.5.4. The qualitative data and its analysis will be used to explain in a greater depth the statistics gathered (Creswell, 2003).

As research design can be exploratory whereby "... the researcher may even change the direction of the study to a certain extent ..." (Dudovskiy, 2016, para .2) some factor relationships were highly significant. The role of the theory of planned behaviour (TPB) was explored. For example, the factor personal behavioural control (PBC) proved to have some significance within my study (see Section 6.1.5). Because of this significance, more than the attitude factors from the theory of reasoned action (TRA) were explored. The research design became exploratory in nature looking at a range of adoption theories (see Section 4.5).

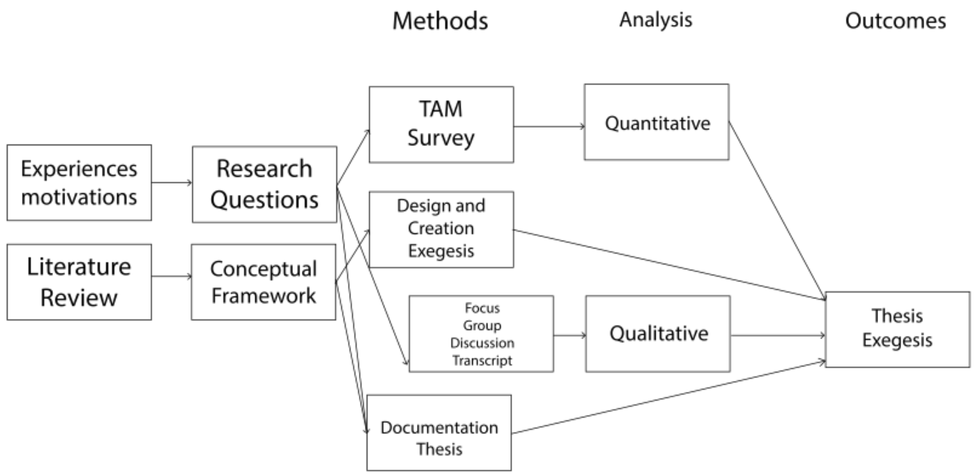

FIGURE 5.2: Research design

A summary of the methods used in TOAOCP is provided in the following table and also how the research methods relate to the research question and/or hypotheses. As discussed, the hypotheses were established retrospectively (see Chapter 4, Section 4.5.5) and were introduced in the literature review in Section 5.2. The results of the hypotheses testing is discussed in detail in Chapter 6, Section 6.1.9.

TABLE 5.1: Summary of research methods

Method	Description	Research Question Hypothesis
Structural equation modelling (SEM)	What are the impacts on cognition of using pictures in learning computer programming?	Research Question One
SEM	What are the impacts on motivation of using pictures to learn computer programming?	Research Question Two
SEM	How are a Year 8 student's values and beliefs about computer programming impacted through using a visually designed lesson?	Research Question Three
Linear regression	Participants who intend to learn computer programming more, also report the pictures as being more useful.	H1p
	Participants who find the pictures to be more useful also report having more fun and enjoyment when learning computer programming.	H2p
	Participants that have more fun when learning computer programming through pictures, have less fear of it.	H3p
	Participants that find they have more prior knowledge about computer programming, believe the pictures to be more useful.	H4p
	Participants with more understanding of the pictures about programming, also rely more on their prior knowledge.	H5p

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Method	Description	Research Question Hypothesis
	Participants with more motivation when learning programming through the pictures, also report understanding programming more.	H6p
	Participants with more ability to learn programming through pictures, also report they understand the pictures more.	H7p
	Participants with more intent to learn programming through a comic, also report higher belief in their personal ability to program.	H1c
	Participants with more personal ability, also report placing more importance on what friends and family think of them learning through a comic.	H2c
	Participants with more understanding of pictures when read in sequence, also report having higher belief in their personal programming ability.	H3c
	Participants with more strategy, report having lower fear of learning programming through a comic.	H4c
	Male and female individuals differ in their intent to learn programming through a comic.	H5c

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Method	Description	Research Question Hypothesis
	The more an individual cares about what their friends and family think about learning computer programming from a comic, the more an individual believes they understand and can read the comic well.	H6c
	Participants that are older, report caring less about what their friends and family think about learning computer programming through a comic.	H7c
Focus group (Participatory design) Narrative design	How does learning with a visually designed artefact have an impact on a Year 8 student's values and beliefs about computer programming?	Research Question Three
Iterative design	Examine the impacts of a learning comic in developing positive impacts toward the learning of computer programming and adolescents.	Research aim
Prototyping	The prototypes are an outcome from the research.	Prototype construction
Thesis	The picture framework is an outcome from the research.	
	Findings and infographics are an outcome from the research of which some components will come from the creative component.	

Data collection expert Professor David Morgan states that a paradigm is a set of shared beliefs within a group or community of researchers (Morgan, 2007). These researchers also share a consensus about meaningful questions as well as the procedures of measurement for these issues. A technology acceptance model is an accepted way of measuring how well a particular medium is accepted amongst researchers. The technology within my research is the picture and comic book delivery. The TAM model has been chosen as a method for quantitative analysis within the epistemological research paradigm. The quantitative research component of the design provides numerical data that will reveal an indication for or against the research questions (Creswell, 2013).

Dr Ernest Dichter, a pioneer of motivational psychology, coined the term *focus group* (Ames, 1998). Focus group discussions are classed as qualitative research and are group interviews where participants are asked their perceptions, beliefs, attitudes and opinions concerning a concept or idea. During the discussion, questions are asked within an interactive group. Here the participants are free to talk to each other. The qualitative research component, that is, the focus group discussions in TOAOCP, have been included to contextualise the experience of the participants in the study. The focus groups added to the findings from the quantitative study. This element is also necessary to triangulate the quantitative data. Generalisations that may result from the quantitative analysis will be analysed more accurately by collecting the qualitative data. The opinions and experiences of the participants are critical and qualitative methods of data collection are particularly suited to this. The approach within the focus group discussions also includes participatory co-creation and iterative design in the form of prototyping.

Epistemological research uses a combination of qualitative, quantitative and mixed methods as a foundation to conduct the study through. The next chapter discusses the methodology of TOAOCP.

5.2 Conceptual framework and hypotheses development

The study is positioned between the disciplines of visual communication and computer science. Design research is relatively new in education, and particularly that of graphic design in the learning of computer science. TOAOCP aims to give graphic design a role in the learning process. The persuasive models produced within this research will consider the role of graphic design within complex learning. Figure 5.3 is a diagram of the conceptual framework developed for TOAOCP.

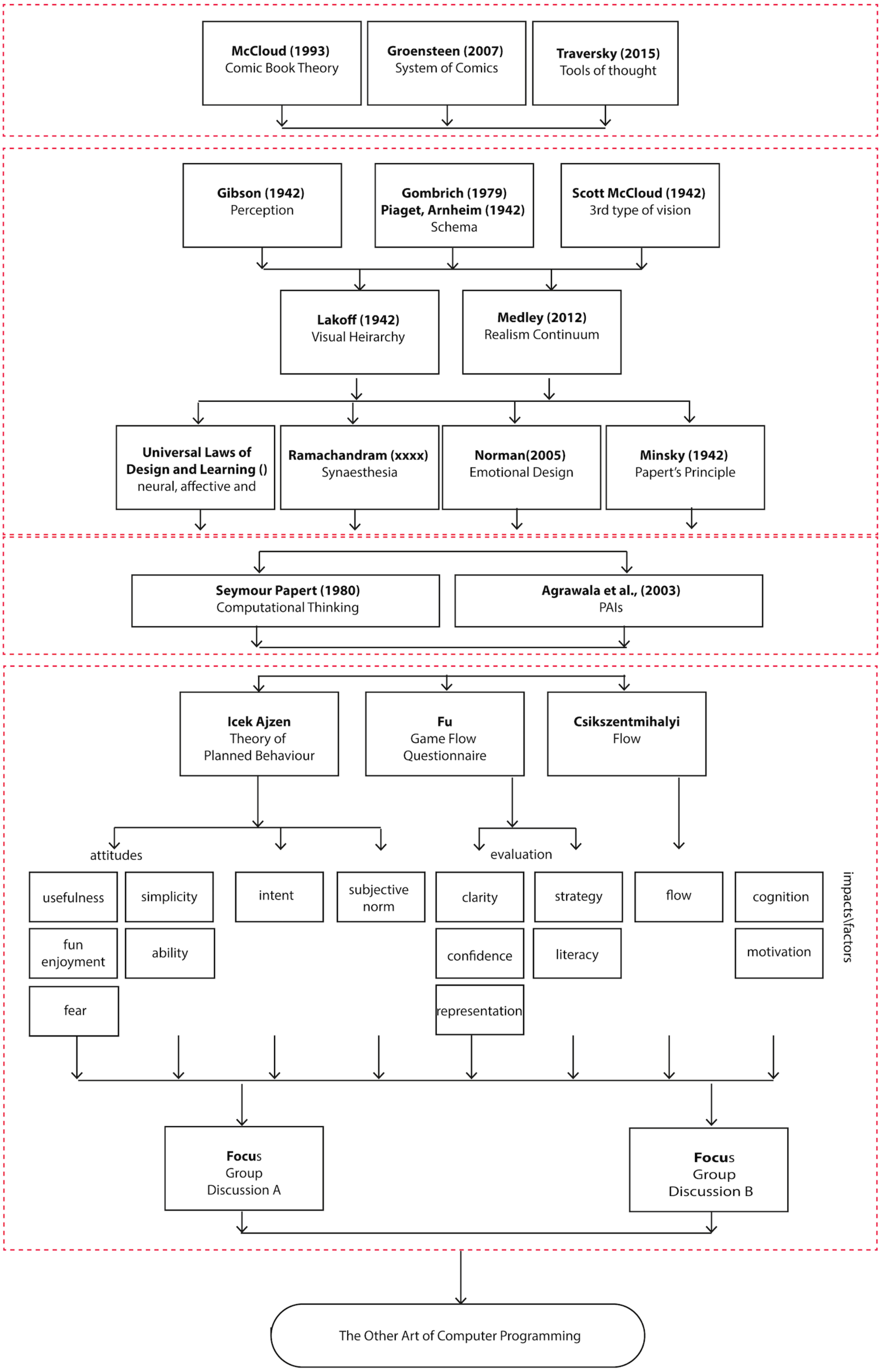

FIGURE 5.3: Conceptual framework for TOAOCP

The four different areas of the conceptual framework align with the sections in the literature review and feed into the development of the hypotheses. The first section on pictures (see Section 4.2) deals with perception and what features can be manipulated with graphic design to enhance communication and didactic purposes. The first section contributed to the hypotheses on pictures (see H1p - H7p). The second section on the psychology of how pictures work (see Section 4.3) deals more with the interpretation of pictures. Z-path, realism and schemata help to explain the retrospective establishment of the hypotheses on comics. The third section in the literature review (see Section 4.4), addresses visual approaches in computer science and examines the reasons why these approaches have not been adopted widely to teach computer programming. The retrospective hypotheses developed are now addressed individually.

> H1p: Participants who intend to learn computer programming more, also report the pictures as being more useful.

H1p was tested to understand the impact of usefulness upon intent to use pictures when learning. Given Tversky's account of various picture types and how these assist learning (see Section 4.2.4) as well as Schumacher's compiled guidelines on pictorial assembly instructions (PAI's) the factor of usefulness was measured. Therefore, if a child sees pictures as useful tools and devices, it follows that they might intend to use these in the future when learning complex information.

> H2p: Participants who find the pictures to be more useful, also report having more fun and enjoyment when learning computer programming.

According to the results (see Section 6.1.3) pictures were indeed fun, and were the salient predictor increasing the intent to learn computer programming, as the fun experienced in learning increased with pictures. Much research exists about the fun of learning through gaming (Iten & Petko, 2016) and software (Sim et al., 2006), however, specific learning of computer programming through pictures and its relationship to fun has not been much of a research focus. As Venkatesh et al. (2003) found fun to be a minor factor to anticipated enjoyment when learning, TOAOCP found that fun and enjoyment was a main predictor (see Section 6.1.3).

H2p represents the link between learning and fun. The link has been researched extensively within the acceptance of technology (Venkatesh et al., 2003) and within education and educational games (Giannakos et al., 2012). Fun and learning have also been extensively researched (Okan, 2003; Sim et al., 2005; Noone & Mooney, 2018). It was also an aim of the picture research to clarify that pictures enhance cognition and are a necessary part of the learning process. Unlike some other elements in learning that are fun, pictures do not distract the learner from engaging with learning content. Paas, Renkl, and Sweller (2003) found that the presence of some fun elements in learning increase cognitive load (see Section 6.1.5).

> H3p: Participants that have more fun when learning computer programming through pictures, have less fear of it.

Three items measured the factor of Fear within TOAOCP. These three items were statements that were designed to assess the understanding of the pictures, the interpretation of the pictures and making a mistake in the lesson because of the pictures. The items were worded so as to assess the level of awareness that the participant had of visual communication. If a student was conflicted about the meaning of a picture, this conflict would decrease the amount of fun had when learning from pictures.

> H4p: Participants that find they have more prior knowledge about computer programming, believe the pictures to be more useful.

This hypothesis was important in order to establish whether or not the students were relying on existing mental models of programming to interpret the pictures when learning to program. As the instrumentation was constructed for novices to learn from, I wanted the meaning of the pictures to be understood without any reliance upon pre-existing knowledge that an adolescent may have about the subject of programming. This hypothesis aligns with the idea that the students were not relying on prior knowledge, as the data did not support the hypothesis. Section 6.1.9 discusses this effect.

> H5p: Participants with more understanding of the pictures about programming, also rely more on their prior knowledge.

This hypothesis was found and is detailed in the results (see Section 6.1.9). Cognition has been defined previously in Section 4.5.4. The relationship presented between these two measured variables requires further research and investigation to see if the hypothesis remains true in TOAOCP. The expected result would have been a decrease in reliance upon prior programming knowledge once a participant perceived that they understood the pictures.

> H6p: Participants with more motivation when learning programming through the pictures, also report understanding programming more.

Self-assessed motivation and self-assessed cognition influenced each other within TOAOCP and motivation in TOAOCP is self-assessed (see Section 4.5.4). The extent to which a learning tool is perceived to be useful in explaining and persuading an adolescent about a topic, increases the motivation to learn programming with that tool. Learning here is a goal-directed activity. A measure of successful learning is cognition, so it would follow that an individual who believes that they understand the material is more likely to achieve their goal (Boekaerts, 1996). Behaviour in education is goal-directed, and the theory of planned behcaviour (TPB) was developed to help predict this behaviour (Azen & Madden, 1986; Ajzen, 2012; De Leeuw et al., 2015). Achieving goals is a motivational aspect of learning (Ames, 1992; Hattie, 2008; Valle et al., 2003; Schunk et al., 2012).

> H7p: Participants with more ability to learn programming through pictures, also report they understand the pictures more.

As an adolescent understands the pictures more, their personal ability in computer programming increases. Section 4.5.4 discussed Social cognitive theory. According to

Bandura's original model of causality, thoughts regulate actions and furthermore " ... what people think, believe, and feel affects how they behave" (Bandura, 1985, p. 5). Cognition according to Bandura plays a critical role in people's capability to self-regulate, learn and perform behaviours. Therefore, the more an individual believes that they understand pictures, the more their personal ability in programming would increase. A background or prior education in visual rhetoric, which is about what persuasive meaning pictures can convey, would assist an individual in learning from pictures.

The above hypotheses were also designed to give richer answers to the research questions concerning the effects of pictures upon the learning of computer programming. The next section in the conceptual framework establishes the hypotheses on the comic design element within TOAOCP. According to Branscum and Sharma (2009), "The history for comic use in health promotion is quite profound". There is a plethora of academic research that utilise comics as interventions, for example as a tool in healthcare and medical studies (Branscum et al., 2013; Dobbins, 2016; Rosas-Blum et al., 2018), and lastly to examine an individual's intent towards a specific behaviour (Hou et al., 2014). However, there are few studies that examine the actual comic attributing any influence to the pictures in sequence within the comic. Studies acknowledge the role of comics in behavioural change as a component within part of a larger solution (Martens et al., 2005). However, comics are not often explicitly measured as being a cause of behavioural change. The next set of hypotheses, relating to comics was developed retrospectively through exploratory research.

> H1c: Participants with more intent to learn programming through a comic, also report higher belief in their personal ability to program.

This hypothesis concerns the factors of intent and personal ability. As intent to use a comic increases so does the individual's belief that they can program. Personal ability or self-efficacy is a salient predictor of motivation and learning (Zimmerman, 2000). Furthermore, perceived self-efficacy exerts a strong influence over cognitive development and functioning. In a study on gender differences, in a programming class that used Lego/LOGO instruction, associate Professor Sally Beisser found that females were just as intent as males on learning programming, and furthermore, females also developed significant gains in self-efficacy (Beisser, 2005). TOAOCP also found that an all female computer class (group three) scored highest on test scores (see Section 6.2.1).

> H2c: Participants with more personal ability, also report placing more importance on what friends and family think of them learning through a comic.

This hypothesis seeks to understand if a relationship exists between how well a person feels that they can program through using a learning comic and how their friends and family feel about the use of the comic to learn programming. There are no studies on the subjective norm (SN) and if it is related to self-efficacy and learning from a comic. These two factors correlate and align TOAOCP with TPB (De Vries et al., 1988; Ajzen, 2002a, 1985).

> H3c: Participants with more understanding of pictures when read in sequence, also report having higher belief in their personal programming ability.

Within TOAOCP strategy was a factor that emerged strongly from the factor analysis (see Section 6.1.5). Section 6.1.10 explains the results concerning strategy. Strategy was a measure that appeared significant within comics that did not appear in the picture factor analysis and may be related to navigating through information (see Section 4.2.1). This would indicate that cognition of a picture sequence, as in a comic, involves a navigational process within the brain. On the other hand, pictures were not navigational, that is they were not understood for what they represented in contrast to how the participants navigated the meaning in comics. There thus appeared to be a different type of processing occurring for the understanding of pictures and the understanding of comics. Whichever processing was occurring, as strategy increased so did the participant's self-efficacy and programming. Therefore the easier the layout of the picture sequences are to navigate, the easier the participants can learn to program. H3c could also be related to cognitive load (see Section 6.3.3) and is worth investigating in future research.

> H4c: Participants with more strategy, report having lower fear of learning programming through a comic.

This hypothesis was established to examine the effect of navigation within a comic and the lessening of Fear or anxiety when learning programming. The easier a comic is to use, the less anxiety a participant will experience when learning to program. H4c comes from extensive cognitive research into comics and Z-paths, usually through eye tracking (Foulsham et al., 2016b; Cohn, 2014).

> H5c: Male and female individuals differ in their intent to learn programming through a comic.

TOAOCP was an investigation into the cognitive processing of pictures and pictures in sequence and the understanding of programming. Gender was not initially a focus within the research, however, 'gender type' was one of the descriptive variables that was part of the data gathered. The mean between males and females as regards intent to learn through a comic was significantly different. The difference of gender upon purpose is discussed in Section 6.1.9. The gender balance of females to males in the computer science industry has been a long-standing debate. More specifically, the male to female ratio within programming is an ongoing area of research (Chen, 1986; Shashaani, 1997; Papastergiou, 2009; Cheryan et al., 2011; Scherer & Siddiq, 2015).

> H6c: Participants that care more about what their friends and family think about learning computer programming from a comic, also report higher belief in their ability to learn from a comic.

The support from family and friends when learning through a comic, impacts upon the strategy or focus that an adolescent has when learning in this way. Here the nature of the factor 'Strategy' might also be under investigation. The Strategy factor could be another measure of focus or flow. Flow is discussed in relationship to comics further in Section 6.1.8.

> H7c: Participants that are older, report caring less about what their friends and family think about learning computer programming through a comic.

Age moderates the hypothesis established in H6c. Peer influence (SN) has less influence on the way that individual learns programming as the person gets older. In other words, it matters less what friends and family think about the way an individual learns. Technical confidence and SN have been a research focus in the way that training formats for different age groups can facilitate positive interaction (Arning & Ziefle, 2007).

5.3 Research plan

Table 5.2 is a summary that lists the methods and activities alongside the dates that they were carried out in TOAOCP. A discussion of the Table 5.2 now follows and forms the research plan. The preparatory phase of the research covered my confirmation of candidature and ethics clearance from Edith Cowan University (ECU) and the Western Australian Department of the Education (DoE). Phase One involved the coordination of the project between stakeholders, construction of the instrumentation, pilot testing and some curriculum development. Phase Two involved the collection, the revising and the analysis of both quantitative and qualitative data. Finally, Phase Three involved writing the results and findings along with the integration of the milestones (see Appendix A) into the final document. Phase Three also included an update of the written thesis, stage by stage. A summary of the research phases is listed in Table 5.2, and a detailed discussion of each phase now follows.

5.3.1 Phase One

During this phase, the instrumentation (or treatment) was formulated together with the pretest (t0), actual cognitive test (t1), posttest (t2) and evaluation (t3) questionnaires. Five teachers selected computing milestones from each decade across the 1950s to 2000s that were then recorded on the secure wiki. These teacher milestone selections have been listed in Appendix F.

The recruitment of participants occurred during this stage. Both the discriminant and convergent validity of the data obtained in the instrumentation were assessed, and aligned with the literature review. The pilot test also occurred in this phase after the construction of the instrumentation. Sixty pages of the lesson prototypes were constructed during this phase of research, including sketches and high fidelity prototypes.

TABLE 5.2: Summary of research phases

Phases	Activity	Description and outputs
Preparatory Phase (July 2015 – July 2016)	Confirmation of candidature Ethics clearance	Approval of proposal granted by ECU and DoE Ethics approved from both ECU and DoE
Phase One (August 2016 - September 2016)	Schools are approached, teachers are organised and permissions are obtained from schools and parents. Pilot test occurs.	Curriculum is initially designed and further literature review is taking place. Stakeholders are consulted about initial high fidelity prototype as in Appendix A. The pilot test will check the instrumentation developed.
Phase Two (September 2016 - December 2017)	Participants take pretest (t0) Participants fill in the instrumentation Participants take posttest (t2) Focus groups are run	Data are gathered and analysed to inform focus group discussions.
Phase Three (January 2017 – March 2018)	Data from the quantitative and qualitative methods is analysed through triangulation. Findings are summarised from the data collections at the schools.	Thesis is written.

5.3.2 Phase Two

Phase Two consisted of the participants completing the instrumentation. In other words, in this phase the data collection took place for the quantitative instrumentation. The data from the pretest (t0), actual cognitive test (t1), posttest (t2) and evaluation items (t3) was collected and stored securely. As paper prototypes were used for the instrumentation, the questions were modified accordingly to suit the media; specifically items for assessing feedback and interactive help were omitted as these were not relevant with the paper prototype.

I performed the data collection. After the quantitative questions had been answered by a number of the participants, the focus group questions were compiled and two focus group sessions were run. The Phase Two outcomes consisted of over 60 pages of lessons, which were guided by the data samples from the instrumentation. The key findings were then summarised and included in the thesis.

5.3.3 Phase Three

This phase involved the synthesis and interpretation of the results based on the data collected from the pretest (t0), actual cognitive test (t1), posttest (t2) and evaluation (t3) (see Appendix A). The triangulation of both the quantitative and qualitative data collected also occurred in this phase. The outcomes were the thesis and part of the creative practice within TOAOCP. Upon completion of this phase the research findings were distributed as a summary to the stakeholders.

To summarise, the research plan consists of three phases involving a mixed methods analysis. Phase One finalised the construction for the instrumentation and coordinated the stakeholders and participants. Phase Two collected the data from the quantitative instrumentation and built the qualitative methods. Lastly, Phase Three disseminated and analysed the data collected from the previous phase. The research summary phases are listed in Table 5.2, while a detailed description is provided in Table 5.3.

5.3.4 Active recruitment

Schools were solicited through my industry contacts and pre-existing relationships that I had with some schools (see Chapter 1, Section 1.1). Teachers were used as intermediaries within the focus groups. Letters were sent for each prospective group to seek parental consent and assuring confidentiality. Participation was entirely voluntary and this was made explicit in all the communications. These communications are included in Appendix G.

TABLE 5.3: Detailed listing of research phases

Milestone	Start date	Deadline
Proposal approval	October 2015	December 2015
ECU ethics clearance	July 2015	December 2015
WA department of Ed clearance	July 2015	December 2015
Stakeholder contact	May 2016	December 2016
Instrumentation	April 2016	December 2016
School 1000	April 2016	June 2016
School 2000	May 2016	June 2016
School 3000	May 2016	June 2016
School 4000	June 2016	August 2016
School 5000	August 2016	September 2016
School 6000	August 2016	September 2016
School 7000	September 2016	November 2016
*School 7050	September 2016	November 2016
Focus Group 3000	November 2016	December 2016
Focus Group 6000	November 2016	December 2016
Preliminary data analysis	August 2016	December 2016
Primary data analysis	November 2016	February 2016
Transcriptions	November 2016	December 2016
Qualitative data analysis	December 2016	March 2017
Thesis draft 1	April 2017	May 2017
Thesis draft 2	May 2017	July 2017
Thesis draft 3	July 2017	August 2017
Thesis draft 4	September 2017	October 2017
Thesis draft 5	November 2017	January 2018
Submission	February 2018	March 2018
* School 7500 added retrospectively as the 7000 group was not random.		

Interactive communication occurred between the Year 8 students and myself concerning the research criteria (see Appendix G). There was also a communication between the class teachers and the Year 8 students regarding the recruitment. I explained that the project was voluntary and the letters (see Appendix G) to the parents reiterated that. The teacher recruited the students by asking the class if they would like to take part in a research project on computational thinking. After this, I collected all the data from the students myself through the instrumentation. The students were made aware that they could withdraw from the study at any point in time up until the data collection finished.

5.3.5 Instrumentation

Although the instrumentation was initially designed as an interactive e-book, due to a shortage of iPads available for TOAOCP, these e-books had to be converted into mini comic books. It was these that were distributed to the participants as the instrumentation. This non-digitised version only affected the items in the instrumentation slightly. As has been discussed previously (see Section 4.5.3), two elements - the interactive feedback and online help were excluded from the e-book. The printed versions of the instrumentation were coded and disseminated to the students by myself during their 40 minute lesson. At the end of the lesson, I then collected the comics, entered the data into a spreadsheet and the hard copies were stored in my supervisor's office. The results are stored electronically on my computer and are only accessible by password.

This ends the discussion on the research plan. The participant sample and population used for the quantitative analysis of the data gathered in Research Phase Two is now discussed.

5.4 Participants

The Year 8 population of students within Western Australia numbers well over 20,000 children, and it was beyond the scope of this research project to involve them all in the study. As stated in the literature review, this project aligns with the Piagetian cognitive stages of development. Section 4.3.5 addressed how computational thinking is suited to a Year 8 student. At this age, according to Piagetian theory, the ability for formal abstract operations occurs as part of the children's developmental stage. The sample for TOAOCP was drawn from seven schools in metropolitan Perth and one in a country area. The participant group therefore came from eight schools. The sample was reflective of schools that agreed to participate in the study. Initially, there were 97 samples collected from Year 8 participants. The first school group contained 27 participants and given this the sample was still on target to reach approximately 300 participants. However, during the collection of the second sample group, there was a dramatic reduction in the proposed number of participants by 66 %. The remainder of the school groups were also reduced by approximately the same percentage. Upon enquiry to why the classes were the size they were, there was no explanation offered. The unexpected reduction in numbers could indicate that this class had become an optional subject instead of being a mandatory one.

One sample proved not to be a random sample. Upon enquiry, this group (Group Six) did not satisfy the 'at random' criteria and so their data was removed from the collection. This group was academically stacked (scholarship students) and were not at random. All other student participants attended their computing, or technology, class, as these are the classes where programming concepts are normally taught. Permission to run TOAOCP was sought through the Information Technology Director (ITD) at each school. The Information Technology Director (ITD) positions had the most credibility with the school principal as these stakeholders often taught programming either separately from or alongside the high school technology teachers (sometimes called design teachers). The first permission to run TOAOCP was obtained from the Information Technology Director (ITD) as they are responsible for deciding the programming curriculum for the Year 8s.

The participants from the schools were randomly selected, that is, the children who participated were not from a particular academic group. In saying this, one group however did not fall into the random selection category, and because of this was excluded from the analysis. The groups in the sample of TOAOCP were drawn from a range of schools, from government to a private girl's school.

The Year 8 cohort at government schools in 2014 numbered 16,993 students (Department, 2015). No boys' schools were included in the study as they declined to participate. Initially, the sample size was on target to be over 300 students, however, the number of students within the classes reduced in 2016 by 66 %. All of these schools were in the Perth metropolitan area except for one. There was no selection process for individuals in the classes involved, and every Year 8 student in the sample was given the option to participate in the study. One child's parents declined to allow them to participate, and only one adolescent, out of a total of 97 participants, decided he would not take part in the study. The participants were students that teachers recruited from their information technology classes.

5.5 Measures

The measures for both pictures and comics have been discussed in Chapter 4, Section 4.5; summarised in Table 4.16 and lastly, a further full break down by item was listed in Table 5.5.1. Examples of two the design elements were created within the instrumentation, and used to measure the participants' intent to learn, and knowledge transfer of computer programming from the artefact to the participant. The study was a hybrid design using a series of illustrated, sequenced questions to gather data. The use of visual communication provided a novel alternative to the traditional point and click tuition style used to teach computer programming.

The methods used to complete the quantitative study of TOAOCP are in the following sections. The research design, instrumentation development, sampling, data collection and analysis are covered. The quantitative data analysis contains two parts, these are:

- Preliminary data analysis;
- Structural equation modelling (SEM) procedure.

The first analysis procedure readies the data for quantitative analysis as well as exploratory factor analysis (EFA). The second step, uses a structural equation modelling (SEM) procedure processed in two stages.

The variables that form the central themes behind the study will now be examined. These themes are the theory of planned behaviour and technology acceptance models (TAM). The behaviour of the participants was measured along with their acceptance of the prototypes as a learning artefact.

5.5.1 The observed variables in TOAOCP: Intention, attitudes, subjective norm, perceived behavioural control, clarity, cognition and motivation

The definition of the above variables was discussed in detail in Section 4.3. Intention, attitude, subjective norm and perceived behavioural control (PBC) are the measures that form the theory of planned behaviour (Ajzen, 1991b). These measures were scales adapted from Iten et al., (2014) which was a study measuring gaming technology that also used a technology acceptance model (TAM). The aspect of the e-learning game that was measured was intention to learn through a game, the subjective norm or what friends and family think of learning through a game as well as the attitudes towards learning through a game.

The details of the adaption of the e-learning game in the Iten et al., (2014) study to TOAOCP are now addressed. As the technology acceptance model (TAM) constructs are derived from the (TPB), the scale was used for both theories. As the theory of planned behaviour (TPB) used the variables of subjective norm and perceived behavioural control in addition to the attitudes measures of the TAM, the variables were included as a measure in the evaluation section of the survey (t3). The items were measured on a Likert scale. Likert scales are defined as:

> . . . those scales where respondents express their STRENGTH OF AGREEMENT with each of several statements, typically with an odd number of response options varying from 'strongly disagree' to 'strongly agree'. (Wuensch, 2005)

The Likert scale in TOAOCP contained 5-points where a "1" meant that the participant "strongly disagreed" with the item and "5" meant they "strongly agreed". As discussed previously, the subjective norm was only measured for comics and not pictures because of the claims of a social stigma that is sometimes connected with comics (see 4.5.1). Table 5.4 lists the constructs and items that made up the factors for the theory of planned behaviour (TPB) and the technology acceptance model (TAM).

TABLE 5.4: Intention, Attitudes, SN and PBC, CLG, MLG, SAC, SAM and Clarity.

Constructs-factors		**Design element and items**
INTENTION (Iten et al., 2014) TPB and TAM	Pictures (Dependent)	1.16: I expect to learn something about computer programming if I use pictures.
		1.17: If I experience a lesson on computer programming in the next few months, I think I will learn something.
		1.18: I want to use pictures more often when I learn computer programming.
	Comics (Dependent)	2.16: I expect to learn something about programming in the future if I learn with comics.
		2.17: I think I will learn something in the future about programming.
		2.18: I want to use comics more often when I learn.
SUBJECTIVE NORM TPB	Pictures	
	Comics (Independent and Dependent)	3.40: My friends would like if I learnt through this type of comic.
		3.41: My parents would like if I learnt through this type of comic.
		3.42: My family would like if I learnt through this type of comic.
ATTITUDES TPB and TAM (Fu et al., 2009) (Venkatesh et al., 2003) (Iten et al., 2014)	Pictures (Dependent)	
	Comics (Dependent)	Usefulness
		1.1: I learn better with pictures.
		1.2: I learn facts faster with pictures.

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Constructs-factors		Design element and items
		1.3: When learning with pictures, I will probably understand it better.
		Simplicity
		1.4: Learning with pictures would be easy for me.
		1.5: I would be good at learning with pictures.
		1.6: It would be easy for me to learn computer programming with pictures.
		Personal Ability
		2.10: I would be able to learn computer programming with comics even if nobody was helping me.
		2.11: Given time I can work out computer programming without a comic about programming to help me.
		2.12: I know enough about comics to use them to study computer programming on my own.
		Fear
		2.13: I'm afraid I might break/rip the comic in the lesson.
		2.14: I'm afraid I might turn to the wrong page in the lesson.
		2.15: I'm afraid I will not understand the lesson.
PERCEIVED BEHAVIOURAL CONTROL PBC (Iten et al., 2014)	Pictures(Dependent)	
	Comics (Dependent)	3.37: Using this type of comic is entirely within my control.
		3.38: I have the knowledge and ability to use these type of comics.
		3.39: I am able to skilfully use this type of comic.

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Constructs-factors		Design element and items
USE OF PRIOR KNOWLEDGE Evaluation (Iten et al., 2014) (Fu et al., 2009)	Pictures and comics (Dependent)	3.4: To complete the lesson it was important that you know a lot about programming.
		3.5: To get through the lesson it was important that you know about programming.
		3.6: To get through this lesson I need to know more about programming.
SELF-ASSESSED MOTIVATION Evaluation (Iten et al., 2014) (Fu et al., 2009)	Pictures and comics (Dependent)	3.22: The lesson increased my interest in programming.
		3.23: Whilst in the lesson I would like to learn more about programming.
		3.24: Because of the lesson, I am more aware of programming concepts.
CLARITY Evaluation (Iten et al., 2014) (Fu et al., 2009)	Pictures (Independent)	3.1: During the lesson I spent time thinking about what the pictures were saying.
		3.2: During the lesson I did not care about what the pictures were communicating I just wanted to finish.
		3.3: I was only interested in learning from the pictures if they explained things the best way to me.
STRATEGY	Comics (Independent)	3.25: During the lesson I spent time thinking about what the comic was saying.
		3.26: During the lesson I did not care about what the comic was communicating I just wanted to finish.
		3.27: I was only interested in learning from the comic if it explained things the best way to me.
CONFIDENCE Evaluation New measure	Pictures (Independent)	3.10: When I learn from picture I feel I learn the right way.
		3.11: When I learn visually, I'm learning the wrong way.

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Constructs-factors		Design element and items
		3.12: When looking at the pictures, I understood the concepts.
	Comics (Independent)	3.28: When I learn from a comic I feel I learn the right way.
		3.29: When I learn visually, I'm learning the wrong way.
		3.30: When looking at the comic I understood the concepts.
SELF-ASSESSED COGNITION Evaluation (Iten & Petko, 2014) (Fu et al., 2009a)	Pictures and Comics (dependent)	3.19: In the lesson I learnt about programming.
		3.20: In the lesson I learnt I should avoid programming.
		3.21: Because of this lesson I am more confident about programming.
PICTURE REPRESENTATION Evaluation New measure	Pictures (independent)	3.16: The pictures explained things.
		3.17: I felt confident I learnt something new with the pictures.
		3:18: The pictures revealed information to me.
	Comics (independent)	3.34: The comics explained things.
		3.35: I felt confident I learnt something with the comic.
		3:36: The comic revealed information to me.
FLOW Evaluation (Iten & Petko, 2014) (Fu et al., 2009a)	Pictures and Comics (independent)	3.7: In the lesson, I was thinking only about the learning from it.
		3.8: In the lesson, I forgot things going on around me.
		3.9: In the lesson, time went quickly.

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Constructs-factors		Design element and items
PICTURE LITERACY Evaluation New measure	Pictures (independent)	3.13: The pictures explained things.
		3.14: I felt confident I learnt something new with the pictures.
		3.15: When looking at the pictures, I understood the concepts.

5.6 Data collection

Printed copies of the instrumentation (see Appendix A) were taken by myself to each group and the participants were asked to answer the questions in the instrumentation during the high school programming class. The data collection took approximately forty minutes for each group. I was available to answer any questions about filling in the questions and Likert scales on the instrumentation. The teachers assisted by turning on the electrical system at the front of the class, thus enabling the instrumentation to be shown on the Smart Board for all to refer to. This occurred in all groups except for Group Two, as the projector was not working at this time. Follow up procedures took the form of an offer to explain the study and run a further focus group, and two schools took part in these, as they were able to schedule time for the focus groups. At the two schools where the focus groups were run, the anonymity of the results was explained to the students. Data collection and follow up procedures took place in a way that the anonymity of the respondents was maintained.

The time ordered sequence of the data collection methods was as follows:

- T(0): Was the pre-test where the students completed a questionnaire before using the learning comic. This questionnaire examined their attitudes toward learning from a comic before the treatment was issued.
- T(1): Was the knowledge test or actual cognitive test (t1), named so because data was collected for this actual cognition during the treatment or while the students were in possession of the comics.
- T(2): Was the posttest, which was the same test as pretest (t0), but issued after the treatment occurred. This was given to the students straight after they completed the actual cognitive test (t1).
- T(3): Was the evaluation section of the data collection. The data collected here was based on the eGameFlow Questionnaire (Fu et al., 2009a).

The scale within this questionnaire contained ten elements as well as the subjective norm. These elements were:

- Attitude;
- Confidence;
- Flow;
- Intention;
- Picture literacy;
- Perceived Behavioural Control;
- Prior knowledge;
- Picture representation;
- Self-assessed cognition;
- Self-assessed motivation;
- Strategy.

In addition to these elements, a measure for the subjective norm was included. The following Table 5.5 is a summary of the instrumentation's construction as well as of the studies that the items were adapted from.

TABLE 5.5: Time ordered delivery of the instrumentation

Time Interval	**Names**	**Model Theory**	**Constructs**	**Sources**
t(0)	Pretest	TRA	Attitude	(Iten & Petko, 2014)
		TAM		(Iten & Petko, 2014)
t(1)	Actual cognition		Programming ability	Researcher's own knowledge
t(2)	Posttest	TRA	Attitudes	(Iten & Petko, 2014)
				(Iten & Petko, 2014)
t(3)	Evaluation	Motivational	Evaluation	(Venkatesh et al., 2003)
				(Iten & Petko, 2014)
				(Fu et al., 2009a)

The data collection phase commenced in July 2016 and a total of eight school groups were visited. This ran for six months and in this time of Research Phase Two, the focus group sessions occurred after the data collections for Group Three and Group Six. To check the validity and reliability of the instrumentation a pilot study was also conducted. A discussion of the pilot study for TOAOCP now follows.

5.7 Pilot study

5.7.1 Primary school pilot

As pilot studies are conducted until validity and reliability of the instrumentation is confirmed, two successive pilot studies were conducted. The first occurred with a primary school to test the validity of the instrumentation. A singular piece of data, that is, the role of pictures, was used for a single calculation in the results to understand the change in perspective by the participants of the role of pictures in learning from primary to high school. No other data from the primary school was used within TOAOCP.

The Year 8s in TOAOCP were mostly thirteen however as most of the primary school students were in fact twelve years of age, the instrumentation (see Appendix A) was reduced; containing only a portion of the questionnaire. Questions in the pre (t0) and posttest (t2) on the comic design element were not included, limiting the pilot study to pictures only. The primary school participants became Group One and performed the pilot study. Only one primary school volunteered to take part in TOAOCP. The ages of the primary school class were eleven to twelve years, and the data was useful to calculate one of the statistics, that is, the role of pictures in learning (see 6.2.4). Data collected in the pre and posttest could not be used. However, the data that measured the difference in what the students believed the role of pictures in learning was valid. The number of questions was reduced because of the age of the children and the risk of survey fatigue. There were 28 responses collected from the preliminary pilot. The primary school teacher requested a feedback session for the students regarding the instrumentation after the data was collected. The primary school students indicated a strong interest in learning programming through visual communication.

During stage one of the research plan, the overall content of the instrumentation was tested on the primary school pilot class. As is the standard with pilot studies, all the responses were used to evaluate the contents, structure and wording of the questionnaire. The comments and responses were also incorporated into an evaluation of the instrumentation. Additionally, reliability was tested for the instrumentation and this resulted in a restructuring of some of the items. Responses for the first pilot test held were invalid as the Likert scale had not been included on the instrumentation. The questions were consequently restructured to include the Likert scale and this was then reissued to a pilot group of students at Year 8 level (Group Two). The initial set of questions on attitude measurement and evaluation for pictures were duplicated for comics as an additional research angle had become apparent during the literature review that linked cognition and comics (Section 4.2.1).

5.7.2 High school pilot

Within the first high school pilot test for pictures, a principle component analysis was conducted to establish reliability and validity (see Table 5.6), this was taken by Group Two, the new high school participant group that numbered 29 (n=29).

TABLE 5.6: Reliability of instrumentation in the pilot test

	Scale	**Cronbach's alpha**	**Cronbach's alpha on standardized items**	**Number of items**
Picture				
Attitudes	Usefulness-Intention	.953	.954	7
	Fear	.920	.922	3
	Personal Ability	.799	.810	3
	Fun and Enjoyment	.916	.922	5
Evaluation	Motivation-Cognition	.935	.938	8
	Prior Knowledge	.912	.915	6
	Understanding*	.649		2
	Clarity	.911	.912	6
	Flow*	.632		2
Comic				
Attitude	Usefulness-Intent-Fun	.943	.946	7
	Fear	.737	.738	3
	Personal Ability-Simplicity	.914	.917	6
	Intent*	.634		2
Evaluation	Motivation-Subjective Norm	.949	.950	11
	Prior Knowledge	.858	.858	5
	Cognition	.802	.811	4
	Strategy*	.662		2
	Flow			1

*As these factors loaded as a two item construct, the Spearman-Brown or split-half measure of reliability was used.

A principal component analysis (PCA) was run on both the picture and comic model as part of the high school pilot test. PCA identifies components related to each other in a set of variables. PCA is defined and discussed under common method bias (see Section 6.1.2). The participant numbers were 47 (n = 47) before the PCA would separate into the appropriate comic factors (unlike the data collected for the picture model that separated into factors with a lower number of participants). The last variable in comics, flow, only loaded one item. Since it is ideal to have 3 items load into each factor in TOAOCP's factor analysis, I had to decide whether or not to continue with the current factors or redo the study. Due to the evidence presented on single-item factors in the next paragraph, TOAOCP continued. More items loaded into flow as I tested more schools and the participant numbers increased.

Since redoing the data collection of TOAOCP was not an option, I researched single-item factors and found that they do exist in some studies however, a larger number of participants sometimes increases the number of items that load into a particular factor. Since flow had begun to separate from the other factors during PCA I decided to continue the data collection. This single-item was high, having a loading value of -.698. Flow is an important factor in TOAOCP; the loading was high and the item and its parent factor were not removed in the pilot test. Many single-item measures are used in statistical studies when the item is unambiguous or the meaning of the item is clear to the user. Single-item measures have been used effectively and extensively in statistical studies (Bergkvist & Rossiter, 2007; Schimmack & Oishi, 2005; Wanous & Reichers, 1997; Williams et al., 2007; Zimmerman et al., 2006). The differences in the studies are as follows:

- Bergkvist and Rossiter (2007) used single-item measures of attitude toward ads and brands and was a business study theoretically based in the social and behavioural sciences.
- Schimmack and Oishi (2005) used single-item measures in the influence of temporarily accessible information of life satisfaction judgements and came from the discipline of social psychology.
- Wanous and Reichers (1997) state that single-item scales can be acceptable. This study came from the discipline of applied psychology and measured overall job satisfaction.
- Williams et al. (2007) study concerned an individual's use of alcohol and measuring their readiness to change. The study was clinical and experimental research. The single-item measures were readiness, importance and intention.
- Zimmerman et al. (2006) was a study from clinical psychiatry measuring symptom severity, psychosocial functioning, and quality of life with reliable and valid single-item measures.

Split-half reliability was used for the factors where only two items loaded from PCA. This type of reliability is a measure that can be used instead of the Cronbach's alpha method of reliability. Cronbach's alpha reliability is traditionally used on a three item measure while the split-half measure of reliability was designed to measure two items. After the pilot tests had been run, I continued developing the prototypes. The data collection was used to inform the creation and development of the prototypes.

5.8 Prototyping

Protoyping is seen in design as one way to navigate through the design process (Innella & Rodgers, 2017). This type of prototyping is effective for the Knowledge Economy and co-creation (Gardien et al., 2016).

Current research suggests that design students become more experienced designers through prototyping in complex contexts (Westerlund & Wetter-Edman, 2017). Through dealing with complex problems, designers become better at their craft. As discussed in Chapter 4, Section 4.2.2, different types of pictures have different purposes. For instance, pictures may be classified according to the level of realism they possess, and this affects the tasks to which they are best put, as was explained to the participants in the focus group discussions (see Chapter 6, Section 6.3.15). These purposes and their impacts upon intent to learn a subject need to be researched at a deeper level. This may lead to the benefits of a visual curriculum being more fully realised. As it is important to critique images (Rose, 2016), in TOAOCP this was specific to students and teachers. Visual realism, as well as the rhetoric an image possesses for the learner can be assessed with the learning process. The TOAOCP prototype that was used with the students elicited information from the participants in the early stages of the design process of the milestones. Through observations, it became clear to me, that the prototype was something the participants wished to create themselves and felt that they could construct it better. This was evident by the level of energy of the participants to the focus group discussion and the subsequent critique, such as "make it less messy" (Tarr, 2016). Participants wanted to construct their own learning comics and show me how to improve the instrumentation.

The design of systems, including those that are interactive, almost always involves prototyping. Prototyping, as part of the design phase, offers a holistic study before the final implementation of a system takes place. Numerous authors acknowledge the role of prototyping in the design of interactive systems (Arnowitz et al., 2006; Chandler et al., 2002; Liu & Khooshabeh, n.d.; Rettig, 1994; Sefelin & Tscheligi, 2005; Snyder, 2003; Zimmerman & Forlizzi, 2008).

Prototyping is defined as the creation of a "... design that allows stakeholders to interact with it and to explore its suitability" (Rogers et al., 2011, p. 386). TOAOCP concerns prototyping only and not the final implementation, which may be part of future studies. The prototypes, in this case, are six lessons each comprising of 20 pages or more of visual instructions. As stated in the previous section, the data gathered in the instrumentation informed the pictures and layouts in the prototypes. Before any of the lessons were digitally designed, they were sketched out as part of the creative process (see Figure 5.8). The first prototype was low fidelity. Hand drawn sketches identified the design elements of form and symbols in the prototypes. Any patterns, such as the software design patterns (see Chapter 4, Section 4.2) or comic panel layout patterns were also established in the low fidelity stage. After the digital sketches were converted into an e-book they became high fidelity. The student participants in the focus group discussions evaluated parts of the high fidelity prototypes (see Appendix A). Questions that were misunderstood, or whose pictures were not highly effective (see 6.2.3), were evaluated by the focus groups and improvements were suggested. Improvements were asked for where there was confusion about the visual rhetoric. Within this research, prototyping was used to test the visual designs before actually producing the final artefacts that formed part of the thesis. These prototypes numbered from one through to six and enabled me to see where there were limitations in this type of curriculum.

The focus group questions were revised and added to at the end of Research Phase One and further revised during Research Phase Two. Participants were asked about some of the interface components that could be added to the existing high fidelity paper prototypes. A mock-up of these components can be seen in Figure 5.4. These interactive components were discussed within the focus group sessions and it was commented by many participants that the added interaction would enhance the initial graphically designed prototypes (see Section 6.3.6).

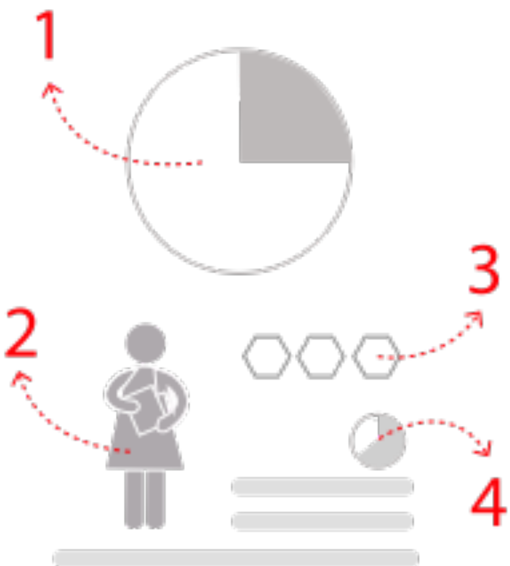

FIGURE 5.4: Interactive components

The graphics within Figure 5.4 are:

1. A timer;

2. An avatar which is standard identification for a login;
3. The milestones achieved;
4. Average time to complete each milestone or lesson.

The prototypes consist of lessons compiled from the literature review from each of the decades of modern computer programming. I developed pictograms on computational thinking intending to cross-reference the pictograms with the prototypes, as all the prototypes contain computational thinking. Early examples of the high fidelity prototypes are listed (see Appendix A). The data collected within the instrumentation was tested and refined in the pilot study until the data was valid and reliable (see Section 5.7). The number of iterations of the prototypes was established upon consultation with the stakeholders and teacher participants in Research Phase One. As a result of the discussions, there was only time for a single iteration in the study. During the focus group discussions, the participants critiqued the look of the lessons and were invited to discuss any difficulties that they experienced with the interpretation of the visual elements.

The lessons were structured to be high fidelity prototypes where the material and visual objects resemble the final product (see Appendix A). The six prototype lessons were completed during Research Phase Three.

5.8.1 Paper prototyping

Good design of an artefact is synonymous with simply making the artefact work better (Norman, 2002). Often if an artefact looks good or even looks correct the layout possesses visual properties that work together with perception to reduce cognitive load when learning. In TOAOCP to examine the visual communication of an artefact a paper prototype was used. In this way, the design elements were isolated from any interactive elements. I created the paper prototype at the beginning of the design process for the artefact, so that pictures and comics were the sole focus of the research. The results section stands alone as being a simple interpretation of the impacts that these two design elements had upon learning. The knowledge forms (these include pictures and diagrams) represented as devices of thought (see Section 4.2.4) of the artefact come first. Interaction designers Vallgrada et al., (2015) highlight the fact that "... computations happen at the speed and in a form and language that are impossible for humans to perceive" (Vallgarda et al., 2015, p .4). Therefore, it is not always apparent what those interactions do, perform, or even in some instances it might not be apparent how they are cued (Norman & Nielsen, 2010). Drawing these interactions as a picture sequence or comic form may be an excellent way to clarify these issues.

The milestones or prototypes within TOAOCP progressed through the following phases listed in Table 5.7. The design of the prototypes was first sketched by hand on paper, then transferred by hand into digital drawing software (Adobe Illustrator), and finally put into either iBooks Author or Indesign. The pictures and the page layouts illustrating the

TABLE 5.7: Prototype stages

Style-Type	**Static or dynamic**	**Software**
Sketches	Static	Pencil, paper
Digital sketches	Static/dynamic	Illustrator

programming processes are drawn using a digital pen into the software. Buxton stresses the need to highlight the difference between sketches and prototypes. This contrast makes sense, as the graphic content could be assessed on its own merits before an interaction designer begins their assessment process of the system architecture. Donald Schön who was the inventor of cognitive design theory and also a cybernetics expert, was quick to differentiate between the respective roles in the development of any product stating that there are two aspects. These are 'the problem setting' and 'the problem solving' within the design process (Schön, 1983; Visser, 2006).

The prototyping process that was undertaken in TOAOCP is summarised in Table 5.8. In designing a learning comic, a designer may need to reassess the traditional two dimensional form that the page takes. The possible programming of the interactive elements may need to take the form of a Z-index that could be a pointer from layer to layer within interfaces. The Z-index is similar to the Z-axis concerning visual hierarchy and marks levels in the design. The Z-axis is opposed to the X-axis and the Y-axis which indicate a two dimensional space.

TABLE 5.8: Prototyping process

Form	**Style**	**Focus group input**	**Interactive**	**Z-axis**
Sketches	Paper sketches	No	No	NA
Digital drawings (Low fidelity prototype) (High fidelity prototype)	Panelling Pictures Text	Yes	No	0
Digital book (High fidelity prototype)	E-books Pictograms Navigation	Yes	Yes	1
	Interactive elements	Yes	Yes	2

5.8.2 The role of sketching in prototype development

According to Buxton (2007), both time and money are saved within the production process of an artefact when the preliminary design has devoted an optimum amount of time to sketching. During Research Phase Two the digital drawings were analysed by the participants during a focus group session.

5.9 Analysis

5.9.1 Data analysis methods

Preliminary steps were taken to prepare the data to be analysed. Preliminary data analysis (PDA) refers to the time period within the quantitative analysis where the researcher gets the data ready for statistical testing. In TOAOCP any missing values were treated in the preliminary data analysis (PDA) with expected maximisation (EM). What this means is that the missing values, that take the form of blank spaces in the data collection, are replaced with values calculated from the values that were not missing; this is explained in more detail in Section 5.9.1.2. After preliminary data analysis (PDA), the exploratory factor analysis (EFA) was performed and then structural equation modelling (SEM) occurred. A summary of the process can be seen in Figure 5.5.

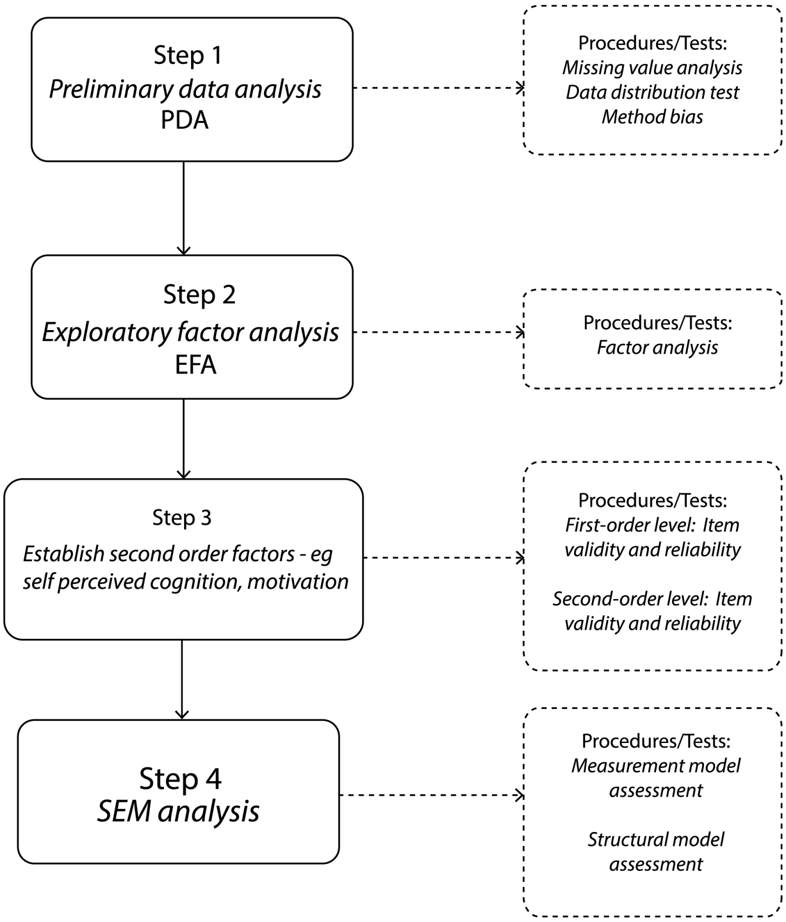

FIGURE 5.5: Data analysis steps, adapted from Matroni (2015a)

A quick search on acceptance models within Google Scholar will return a list of 100s; however, despite this abundance, a visual acceptance model is yet to be established. The impact of using pictures and comics upon the participants intent to learn computer programming was examined in TOAOCP. Two models were constructed, one for pictures and one for comics, for learning computer programming through visual communication. Many different types of software were used to establish these models, as well as to group and analyse the qualitative data. The data analysis procedures that assisted in the construction of the prototypes are now discussed.

5.9.1.1 Data analysis procedures

TOAOCP has used a synthesis of methodologies, and therefore the data analysis is divided into the sections dealing with each of the methods. The data collection was divided into two research categories, the quantitative and the qualitative. The methodology will now continue with a discussion of the quantitative data analysis.

5.9.1.2 Quantitative data analysis

After the data had been collected, the descriptive statistics were calculated. The descriptive statistic contrasts with an inferential statistic that generalises about the larger population it comes from (Webb et al., 1966). The descriptive statistics for TOAOCP are listed in Appendix C. Descriptive statistics on age and gender were calculated that included the frequency and percentage statistics in Table 6.1. The participants self identified their skill set within the categories of slight, basic, social user or advanced computer user. The advanced computer users were described as the participants that had knowledge of programming languages. Participants could choose a single skill set or a combination of any of the four.

As Research Question Three measures the effect of the treatment on Year 8 learners, a Wilcoxon Signed Rank Test was calculated (see Section 6.1.4). A Wilcoxon Signed Rank Test compares the items (within the instrumentation see Appendix A) by measuring them before the treatment occurs, and then measuring the same items after the treatment. These comparisons will be examined to check that they determine the correct information from the sample (Korb, 2014).

The factors or impacts were described in the literature review in Chapter 4, Section 4.5 and are summarised in Table 4.16. Linear regressions were run to test each factor against others within the quantitative data. As this study is an exploratory research design, each factor was regressed as the dependent variable upon the other independent variables. In this way, any relationships could be examined retrospectively. Only significant relationships were reported (see Section 6.1.5).

The TAM is an empirical model which, in TOAOCP, explored the relationship between participant attitude and learning through visual communication. This has been covered in detail within the literature review (see 4.5.3). I searched for a suitable model to measure the elements of motivation, cognition and attitudes during the literature review and concluded that the TAM model was suited to TOAOCP after Research Phase One.

Quantitative instrumentation procedure
Dispensing the quantitative instrumentation to the participants occurred in Phase Two of the research plan as follows:

- Set up whiteboard;
- Give timeline selection to the teacher to vote for lesson selections (see F: I entered the selections into a private online WIKI space after the class);
- Assign instrumentation to the class for 40 minutes;
- Compare the performance of the participants on the pretest (t0), posttest (t2) and then evaluate the treatment.

The data collection phase stayed as above throughout the seven school groups.

Primary software used
For the quantitative component for the analysis, SPSS version 23 was used. SmartPLS (version 3.2.6) was used for some of the SEM analysis and WarpPLS 4.0 was also used for structural equation modelling (SEM) analysis. WarpPLS is a partial least square structural equation modelling statistical program and this was used for the full structural models for both pictures and comics. WarpPLS was chosen because it has a low sensitivity to sample size (Hair et al., 2010). Some of the constructs consisted of less than three items and Ringle et al. (2012) suggest that PLS-SEM is more reliable for these low item constructs. This software also suits non-normal data distribution as was as was the case within the research sample (Davis et al., 1992) (see Section 5.9.1.2).

Smart-PLS was also used in the quantitative analysis to calculate the linear regressions in Section 6.1.5 to Section 6.1.5. This software runs both SEM analysis and linear regression analysis.

Software was also used in the qualitative analysis. NVivo was used in the qualitative analysis to code and classify the data within the focus group transcripts. Answers were coded on themes that strengthened the existing data collected for the quantitative analysis. Summary of the software used in TOAOCP can be seen in Table 5.9.

TABLE 5.9: Summary of software used

Name	Type	Section	Reason
Quantitative			
WarpPLS	SEM	7.1	SEM analysis
SmartPLS	Linear regression	7.1.3.8 7.1.3.9 7.1.3.10 7.1.3.11	Linear regression models
Qualitative			
NVivo	Transcript analysis	7.3.1	Analysing interview transcripts

Preliminary data analysis
The preliminary data analysis (PDA) is a set of treatments performed on the data collected to make sure it is ready for statistical analysis. As quantitative research was performed through a survey data collection in TOAOCP, research bias could complicate the interpretation, limiting how the findings could be used. The design of the instrumentation may produce a bias or the participants can be biased themselves (Davis et al., 1992). The instrumentation may contain unexplained variations within the measurement of the items and missing values. Treatments were performed on the data to keep it free from bias in the PDA.

Treatment of missing values
Missing values hinder statistical calculations and change approximations within the data. Within TOAOCP, the items within the instrumentation (see Appendix A) that contain the

data from the participants, may have missing data. Here the participants may fail to answer an item or more generally, some of them simply may not respond to the survey.

Missing values can be totally at random (MCAR) or missing at random (MAR) or not missing at random (NMAR) (Ajzen, 2011). Each situation is different in regards to the 'missingness'. MCAR or missing completely at random means when an item is missing, this does not affect another variable becoming missing. MAR or missing at random means there is a pattern or the missing value can be predicted. If the data is NMAR or not missing at random then a pattern is identified in the data and the treatment of the data is decided. Imputation is one way of treating the missing data collected. Here the missing values are replaced with an approximation of what their value would be. The data is only ready for analysis once the missing data values have been removed. Imputation follows three steps that are imputation, analysis and pooling, which were developed by statistician Donald B. Rubin in 1987 (Barnard & Meng, 1999). Imputation values can be drawn a few times from the data from many data sets. Each of the data sets is then analysed and lastly, the different data sets are consolidated into one. When consolidation occurs, the mean and variance are calculated for these missing values. Statistical researchers suggest that there should be a 20 % missing-value cut off point (Little, 1988). TOAOCP had less than 20 % missing data within the data set.

Maximisation is a generic term spanning across multiple disciplines. It is defined as "...the act of raising to the highest possible point of condition or position" (Dictionary, 2016). Expected maximisation (EM) is unique to the discipline of statistics and is used within TOAOCP as the way to replace missing values and takes place during the preliminary data analysis (PDA). Statistical data cannot be calculated with missing values within the data set. The EM algorithm was first explained and named in 1977 by statisticians Dempster et al., (Dempster et al., 1977). This algorithm iterates through the data performing an expectation step (E) first and then a maximisation (M) step. The E step calculates an expected estimate of the value while the M step computes a value upon the expected estimate (Rubin, 2004). EM is used a lot in machine learning and computer vision research. Little's test validates missing values within a set of data to be random. This method of replacing missing values proved suitable for the analyses, the data was not significant for Little's test, proving it to be MCAR. Another reason the EM method was used was that it provides unbiased estimates for MCAR patterns (Hair et al., 2006).

Common method bias

This type of bias estimates errors in the measures that represent the constructs. For example, a user interface may prove too complex for participants and bias the answers to the items given. This type of bias (CMB) threatens the validity of the instrumentation. The instrumentation can be threatened by how the data is collected (see 5.9.1.2), instrumentation design or the actual statistical measures that can be responsible for the bias. There are a variety of measures that can combat CMB or help to prevent it. Harman's single factor test signifies whether or not CMB is present in the data, and was used in TOAOCP. When factors are extracted for this test, they are constrained to a single common factor.

By loading all the observed or manifest variables into a single common factor, bias can be found if this procedure yields one general factor that encompasses the majority (Doty & Glick, 1998; Hu et al., 2012a; Podsakoff et al., 2012).

As there was no CMB present in TOAOCP, no measures needed to be taken to combat CMB. A principal axis factoring extraction method was used as in Schmitt (2011). All manifested variables were constrained to a single common factor when Harman's single factor test was run, hence the name single factor. This is also based on an un-rotated factor solution. Rotation of factors is only needed when loadings need to be found for more than one factor. Rotation exposes the patterns of the loading of more than one variable. The data is run as an un-rotated solution so that each factor can maximise the variance that has occurred on the previous factors. The variance estimates the average spread of a set of data (Bennett, 2001; Karanja et al., 2013). If CMB exists, Harman's test will be triggered by one general factor that accounts for more than 50 % of the variance (Field, 2013a).

Data distribution

According to Field, normally distributed data is "... a probability distribution of a random variable that is known to have certain properties" (Field et al., 2012, p. 924). The data must be perfectly symmetrical, have a skew of zero and a kurtosis of zero. Skew is a measure of the symmetry of frequency distribution while frequency distribution is where the values of observations on the horizontal axis and the frequency with which each value occurs in the data set on the vertical axis. Kurtosis is a measure of the tail of distribution, not its peak (Westfall, 2014). The frequency distribution is also called a histogram (Doty & Glick, 1998; Hu et al., 2012b; Podsakoff et al., 2012). More precisely, kurtosis is the degree that the scores cluster in the tail of a frequency distribution. Data satisfying the criteria listed in this paragraph are normal data. Parametric testing can occur on normal data. Both parametric and non-parametric tests were considered for TOAOCP. The data collected were not normally distributed, therefore non-parametric testing occurred. According to Field non-parametric tests are:

> A family of statistical procedures that do not rely on the restrictive assumptions of parametric tests. In particular they do not assume that the sampling distribution is normally distributed. (Field, 2013b, p. 790)

Exploratory factor analysis (EFA) is one of two types of factor analysis that was used in TOAOCP. EFA is used to confirm the existence of the factors and constructs that were established with the TPB and the modified TAM. The next section looks at EFA and how it was applied to TOAOCP in detail.

Exploratory factor analysis

In statistics a factor is "... another name for an independent variable or predictor that's typically used when describing experimental designs ..." (Field et al., 2012, p. 918). Factors are also known as latent variables or unseen variables that have been calculated from that which can be observed or is measurable. In TOAOCP the items are the observed variables. Table 5.4 lists the variables used in TOAOCP and the dependent and independent values for the full structural equation model. Analysis of these factors is "... a multivariate technique that identifies whether the correlations between a set of observed variables stemming from their relationship to one or more latent variables in the data ..." (Field, 2013b, p. 875). The observed variables of each factor are related to each other linearly. That is, a linear model such as the one in Figure 5.6 whereas height increases so does the age of the child.

FIGURE 5.6: Linear model of child's growth from eight to twelve years old

First the individual items are measured and then the factors are derived from these individual measurements depending on how they cluster or rotate. The items load into each factor that they measure through a process of factor analysis. Formally, factor analysis is:

> A multivariate technique of identifying whether the correlations between a set of observed variables stem from their relationship to one or more latent variables in the data, each of which takes the form of a linear model. (Field, 2013b, p. 875)

Exploratory factor analysis is a type of factor analysis whereby the factors are allowed to load naturally into their constructs through settings in the software. This type of factor analysis, EFA is used in contrast to confirmatory factor analysis (CFA) where the factors are forced to load specific items. Both confirmatory and exploratory factor analysis were used within TOAOCP. Confirmatory factor analysis occurs when the convergent validity has reached the required threshold. Convergent validity occurs when an item measures the latent construct for which it was designed. The factors load through a process called extraction.

The process of extraction occurs within the data where groups of observed variables emerge within the software from a statistical calculation. These grouped variables form a collective of factors and are important in the measures taken within the study. TOAOCP used a group of factors that measure Attitudes and were used in a previous study (Iten & Petko, 2014). Participant Attitude is a measure calculated by summarising the following elements of usefulness, simplicity, personal ability, fear and intent to use. Field gives a more formal definition of extraction:

> ... a term used for the process of deciding whether a factor in factor analysis is statistically important enough to 'extract' from the data and interpret. The decision is based on the magnitude of the eigenvalue associated with the factor. (Field, 2013a, p. 875)

Rotation is also part of factor analysis. Some statistical calculations require this and some do not. Factor analysis requires rotation while other forms of component analysis in SPSS are required to be un-rotated. For example, Harman's single factor score used in TOAOCP uses an un-rotated solution to calculate bias that is the opposite of rotation. Field et al. (2012) defines rotation as:

> A process in factor analysis for improving the interpretability of factors. In essence, an attempt is made to transform the factors that emerge from the analysis in such a way as to maximize factor loadings that are already large, and minimize factor loadings that are already small. There are two general approaches ... (Field et al., 2012, p .925)

SPSS version 23 calculated the EFA. The extraction method was principal axis factoring (PAF) with direct oblimin (orthogonal) rotation (Field, 2013b, p. 785). Orthogonal direct oblimin rotation was used because the method represents reality by allowing correlation between the factors. By using direct oblimin, the factors can correlate and represent more than one factor besides the theme they have been selected to measure. A pattern matrix is a product of EFA where the items are loaded into a parent factor together. For example, items examining an instrumentation's usefulness such as item, 1.1, 1.2 and 1.3 should all load into the factor of Usefulness.

Items with minimum factor loadings of .50 on their parent construct and lower cross-loading on other constructs were maintained in TOAOCP. Along with these minimum factor loadings. a further check was applied against eigenvalues and scree-plots to determine the number of factors that should be retained (Allen & Bennett, 2010; Pallant, 2010; Hair et al., 2006; Siponen et al., 2014).

For factors to be considered as distinct and reliable for use in statistical analysis, satisfactory sphericity is also required. The definition of sphericity is as follows:

> . . . a less restrictive form of compound symmetry which assumes that the variances of the differences between data taken from the same participant (or other entity being tested) are equal. This assumption is most commonly found in repeated measures ANOVA but applies only where there are more than two points of data from the same participant. (Field, 2013b, p. 793)

The appropriateness of the factor solutions was checked with both Kaiser-Meyer-Olkin (KMO) and Bartlett's test of sphericity.

KMO values close to 1 means that there are compact patterns of correlation, indicating the factors are distinct and reliable (Pallant, 2010). Kaiser (1974) states KMO values of .50 are acceptable and Field (2013) considers values over .70 to .80 'good' (Field, 2013a).

The correlation coefficients of an identity matrix are all equal to zero, and the test that checks for this matrix is Bartlett's test (Field, 2013). Because correlations and relationships are expected in the matrix, Bartlett's test has to be less than .05 or significant ($p < .05$) to be acceptable (Allen & Bennett, 2010). After the above tests have been examined and passed, the data is ready for EFA. SEM then occurred and is a two stage process starting with stage one, that is, assessing the measurement of the model for its fit to the data.

5.9.1.3 Stage one (PLS-SEM): assessing the measurement of the structural equation model

As discussed, the software used in this stage was SmartPLS 3.2.6 and WarpPLS 4.0. This software analysed the measurement and the structural model for the first-order factors and models within TOAOCP. The model measurements were drawn from authors, Ringle et al. (2012). There must be an acceptable level of discriminant validity and convergent validity within SEM modelling. The average variance extrated (AVE) represents the convergent validity and the inter-construct correlation, item loading and cross-loadings with their respective p-values that determine the discriminant validity. According to (Anderson & Gerbing, 1988; Chin, 1998; Galvin, 2011; Gefen & Straub, 2005; Hair et al., 2011) these methods and criteria are the basis for modelling adequacy.

Multicollinearity is defined by Field as "... a situation in which two or more variables are very closely linearly related" (Field, 2013b, p. 879). This feature could mean the presence of an overarching factor or construct that represents both variables. In this case, the variables would not represent separate factors. The data in TOAOCP, was checked for multicollinearity to ensure the factors did represent the model in the structural equation. Reflective and formative constructs are also examined through multicollinearity.

5.9.1.4 Reliability and validity

There are three different types of validity within this study and all were addressed to ensure the validity of the instrumentation. The content validity occurred through reading references from the literature review. The references concerned technology acceptance models (TAMs) and other theories of adoption (see Section 4.5). This type of validity is the extent to which a measure represents all facets of the factor or construct. The second type of validity is construct validity and involves what a factor claims to measure. Construct validity encompasses both convergent and discriminant validity. If the items have a high measure of this type of validity, then the measure of that construct is valid. Here the factor accurately reflects the specific observed variables. The third type of validity is discriminant validity which tests whether factors are related. The factors in TOAOCP are not supposed to be related. An item is valid if it meets both convergent and discriminant reliability. Estimation of discriminant validity occurs by calculating the square-root of the factor's AVE assessments. The result must be higher than the correlation of the construct with other factors (Moqbel, 2012). The results section addresses reliability and validity at a deeper level and contains details of the statistical analyses that were undertaken (see Section 6.1.8). Table 6.22 lists the AVE values for the full structural equation model.

Item reliability was examined with a measure of each item's loading upon the factor. Hair et al. (2010) states an item is reliable when the loading is equal to or above .50. Cronbach's alpha and composite reliability should be above .70 to guarantee effective reliability (Fornell & Larcker, 1981; Kock, 2013). However, some researchers prefer composite reliability over Cronbach's alpha as the lower bound value of alpha underestimates reliability (Peterson & Kim, 2013). Both reliability estimates are reported in TOAOCP.

Collinearity means that two or more variables within a multiple regression model are highly correlated. One predicts the other with accuracy. The measure for collinearity is average variance inflation factor (AVIF) and also average full collinearity variance inflation factor (AFVIF). The cut-off points proposed by Fornell and Larcker (1981) is 3.3, which is the best result and 5 is acceptable. If values exceed these limits, there is collinearity. Here factor loadings should be re-examined. Hair et al. (2010) reports lower than ten are acceptable. Table 5.10 is a summary of the assessment criteria used for the measurement model.

TABLE 5.10: Measurement model criteria (Mat Roni, 2014)

Assessment	Criterion	Note	Reference
Item Reliability	Individual item standardised loading on parent factor.	Min. of .50	Hair et al. (2010)

continued ...

...continued

Assessment	Criterion	Note	Reference
Convergent Validity	Individual item standardised loading on parent factor, and loadings with sig. p-value.	Min. of .50 p < .05	Hair et al. (2010) Gefen and Straub (2005)
	Composite reliability	> .70	Fornell and Larcker (1981)
	Average variance extracted (AVE)	> .50	Kock et al. (2012) Hair et al. (2010)
Discriminant Validity	Square-root of AVE	More than the correlations of the latent variables.	Urbach N et al. (2010)
Reliability	Cronbach's alpha	> .70	Nunnally and Bernstein (1994) Hair et al. (2010) Hair et al. (2010)
	Variance inflation factor (VIF)	< 10 < 5.0 < 3.3 (ideal)	Hair et al. (2010) Urbach N and F. (2010)
Nature of construct	Formative/reflective	Theoretical assessment Indicator inter-correlation Weight loading sign	Chin (1998a) Coltman, Devinney, Midgley, and Veniak (2008)

5.9.1.5 Reflective latent constructs

Before testing a model in the PLS software, the factors must be determined as reflective or formative. Reflective changes are seen in their observed variables as opposed to formative where the changes in the constructs are reflected in their observed variables. When writing about PLS methods, the word construct will be used instead of factor, and indicator will be used to represent the observed variables. According to Coltman, Devinney, Midgley, and Veniak (2008, p. 689) there is a "... need for researchers to justify, theoretically and empirically, their choice of measurement model" and further:

> Use of an incorrect measurement model undermines the content validity of constructs, misrepresents the structural relationships between them, and ultimately lowers the usefulness of management theories for business researchers and practitioners. (2008, p. 689)

For TOAOCP, a change in one of the constructs like Fun and Enjoyment of pictures would also mean that one of the indicators would change. Formative is the opposite of a reflexive measure where causality flows from the indicator to the construct. For this research a change in one of the items that measure fun such as Question 3: 1.7 "Learning with pictures is fun", would also change the value of the construct of Fun/Enjoyment. Linear regressions were also calculated upon all the constructs to understand the strong correlations or the relationships between each. Table 5.10 is a summary of the measurement model that was used for TOAOCP for the structural equation models.

What now follows is a brief discussion of each measurement used to assess the structure of the models.

5.9.2 Stage two (PLS-SEM): assessing the full structural equation models

5.9.2.1 Coefficient of Determination, R^2

Statisticians researching SEM suggest that the R^2 measurement is mandatory for the evaluation of these structural models. Field gives the term Pearson correlation coefficient squared to R^2 and states it is "... a measure of the strength of association or relationship between two variables" (Field, 2013b, p. 872). The coefficient of determination is "... the proportion of variance in one variable explained by a second variable. It is the Pearson correlation coefficient squared" (2013, p. 872). The R^2 measure is reported as part of the model's statistical measures. The values of .67, .33 and .19 are substantial, average and weak, according to Chin (1998).

5.9.2.2 Predictive relevance, Q^2

The Q^2 or predictive relevance as a measure in SEM is calculated with a procedure called blindfolding, defined as:

> ... is a sample re-use technique that calculates a cross-validated predictive relevance criterion, the Stone-Geisser's Q^2 value. (Geisser, 1974; Stone, 1974)

The Q^2 value is required in the structural assessment of the model. The effect size or strength of a structural model is also measured and reported in SEM. This also represents the strength of the intent factor the models are measuring. The predictive relevance becomes larger when the difference between the predicted and the original values get smaller. Through the observation of values, the predicted values are constructed through a model and certain parameters (Chin, 1998).

5.9.2.3 Effect size, f^2

Effect size is defined as "... an objective and (usually) standardized measure of the magnitude of an observed effect" (Field, 2013b, p. 874). An effect size can be significant but not very strong or large. The effect size may be too small to be considered relevant in some cases.

Cohen (1988) states that the effect sizes .02, .15 and .35 are small medium and large respectively. Cohen's measures are accepted as a benchmark measure of effect size for assessing SEM models (1988).

5.9.2.4 Path coefficient, β

The term path coefficient was first used by Wright (1921). Coefficient paths determine a relation between variables in a multivariate system. Multivariate means 'many variables' and is used where there is more than one outcome variable (Field, 2013b). Path assessment in TOAOCP is a combination of the path coefficient or beta value and value and the p-value of the path. According to Chin (1998), the path value of .20 is the minimum accepted value. The preferred value for the path coefficient is .30. Table 5.11 is the summary of the accepted values used for the structural models in TOAOCP.

TABLE 5.11: Structural model assessment criteria, Matroni (2014)

Criterion	**Note**	**Reference**
Coefficient of determination, R^2	.67 substantial	Chin (1998b)
	.33 average	
	.19 weak	
Predictive relevance, Q^2	> 0	Geisser (1975)
	Stone-Geisser test	Stone (1974)
Effect size, ^{2}	.02 small	Cohen (2013)
	.15 medium	
	.35 large	
Path coefficient,	Magnitude Sign	Hair et al. (2010)
	p-value	Chin (1998a)
	Standardised coefficient	
	.20 acceptable	
	.30 ideal	

5.9.2.5 Model analysis

Models were constructed and run on the data set (N=59) to answer research questions one and two as well as to provide a model of intent to learn computer programming through pictures and then through comics. The analysis allowed attitudes toward the learning comic and programming to be examined on the strength of the structural paths within the models (see Figure 6.4 and Figure 6.5).

The discussion continues with the qualitative analysis of the research.

5.9.2.6 Data analysis for the qualitative data component of the design

The qualitative research component will expose and analyse the role of the design elements according to the participants' experience. The order in which these methods are presented reflects the order that they are presented in the research plan.

Iterative design method
The iterative design method is cyclical in nature being used to plan, test, evaluate and refine a process or a product; early prototyping is one of "... four central ideas ..." (Carroll, 1997, p 65). To elaborate on the use of the prototype, the instrumentation was made and then after the results were analysed they informed the development of the milestones that are prototypes for learning. Within TOAOCP continual refinement of the milestones (Appendix A) occurred. The instrumentation, that was developed within Research Phase One (see Appendix A). Both sketches and high fidelity prototypes were evaluated within the research plan.

The selections made by the teachers on the milestones they believed were necessary to learn computer programming were recorded on a secure wiki (see Appendix F). Based on the recommendations from the teachers, the prototypes were drawn up as the high fidelity milestones included in Appendix A. A single final prototype combining various segments from the milestones, also contained the instrumentation. This instrumentation prototype was used by the group of student participants, and they recorded their answers to the items that formed the impacts and factors. The single iteration of the design occurred because of the limited time for which I had access to the participants. The number of iterations in the research design was determined at the end of Research Phase One.

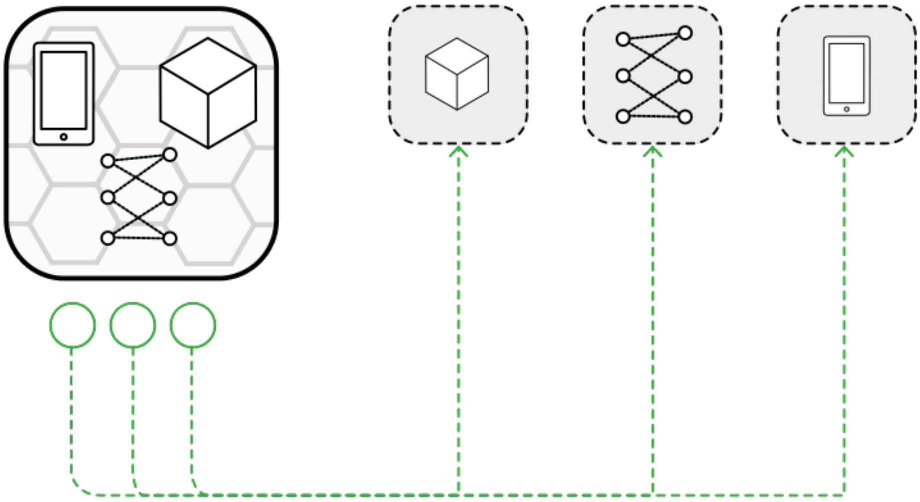

FIGURE 5.7: MVC design pattern

The six lessons were constructed according to feedback received during research phases two and three. The responses of the participants were necessary to guide the development of the lesson prototypes (see Section 5.8). Considering the participants as co-designers in this role is also known as participatory design (see Section 5.9.2.6).

Participatory design
During Phase Two a participatory angle for the research was taken. This type of design includes the research participants by cooperating with them to innovate a process. The participants can contribute to any of the design phases, from the initial exploration to design solutions and evaluations. Participants were seen as equal to myself as the designer within the creative process. As has been ascertained in previous research, the adolescents' opinion was confirmatory and essential to the design process (Spinuzzi, 2005). The participatory design had the additional benefits of drawing attention to problems within the existing prototype or instrumentation. For instance, the issues encountered with interpreting meaning in the pictures were not regarding navigation issues or readability issues, but were mostly concerned with the interpretation of pictures, and this is discussed in the focus group results (see Section 6.3.2).

The first twenty pages within the instrumentation were designed to identify any early problems with:

- Navigation;
- Meaning within the diagrams;
- Issues of readability with the layout, and;

- General semantics.

Participants were asked for their feedback regarding the instrumentation's layout and ease of use. The questions asking for feedback were adapted from information design scholar Peter Storkerson's questionnaire about pictures and text working together (Storkerson, 2003). The participants were asked in these questions whether or not the pictures and words worked together, and if in fact they integrated well. Based on this feedback, together with the actual cognitive test, the participants were asked for suggestions for improvement in the integration of the pictures and words. From all this, both the quantitative and qualitative data were triangulated to provide the researcher with richer information.

Triangulation design
Triangulation is the use of several research methods to study the same phenomena (Bogdan R. C. Biklen, 2006). Denzin (2006) calls multiple methods for gathering data methodological triangulation.

Methodological triangulation was used to inform the creative process as well as to cross-check the results of the quantitative methods. Once the quantitative data had been received in the pre and posttests, the focus group questions were structured to add more in-depth data. The methodological triangulation used in TOAOCP involved the multiple methods of data collection: from the questionnaires administered across the school groups, to the focus group discussions. Triangulation was also used in TOAOCP to limit any weaknesses in the data sources (Martin Hanington, 2012). The large set of data collected in the quantitative instrumentation was combined with more precise data in the focus group sessions. The focus group discussion questions were formulated and then confirmed after the quantitative data was analysed.

Accordingly, any themes that emerged from the quantitative methods are reflected in the focus group discussion questions. Perceptions from the participants on the themes established in the literature review, such as cognition and motivation, were recorded during the focus group sessions. The focus questions established are listed in Appendix A. All data for TOAOCP was gathered through cooperation with a large group of stakeholders.

Stakeholders
Methodologies that include stakeholders also give information on perspectives within a group setting (Nielsen, 1997). Predetermined discussion questions were used to prompt the members of the focus groups for answers. The stakeholders here were also encouraged to give their opinions.

TOAOCP research used the results of the discussions from the focus group sessions and included stakeholder information to guide the construction of the prototypes. The stakeholders that were contacted include:

- Information technology teachers, directors and principals;
- Industry advisors;

- Industry expert – Professor Donald Knuth.

Information gathered from stakeholders took the form of recommendations for visual communication that were the basis of the milestones that are an outcome from Research Phase One (see Appendix A). Information technology coordinators and teachers selected the milestones from a list that they were issued at the beginning of the quantitative data collection (see Appendix F).

5.10 Creative process

The practice component of the project took place during the Research Phases Two and Three. The teachers who took place in the study initially selected six milestones, one for each decade (See Appendix F), to illustrate various programming topics from the 1950s to the 2000s. The six milestones are listed in Table 5.12 below, and form exemplars of TOAOCP:

TABLE 5.12: Six milestones that form exemplars of TOAOCP

Year	**Description**	**Computer Scientist**
1950s	Machine level architect, memory cells	Von Neumann
1960s	LOGO programming	Seymour Papert
1970s	COBOL	Grace Hopper
1980s	Smalltalk	Adele Goldberg
1990s	Web development, HTML, CSS, Ruby framework	Tim Berners-Lee
2000	iOS programming, app development	The gang of four

I have been constructing visual curriculums since 2012 to explain the programming process. The following process was used to construct the learning comic and draws from personal experience:

1. Summarise, reduce technical information to necessary components. Reduce anything that seems superfluous or extra information about the programming process.

2. Draft the lessons out on a page including the panel layout or basic comic format. Groensteen, author of *The System of Comics*, speaks of a concept called gridding and states that this 'grid' effectively incarnates comics as a 'mental form'. He furthermore maintains that the artist can refer to this 'mental form' at a very early stage of creation. This stage is acknowledged in the process of comic creation and is briefly described as "... the first appropriation of the space that is invested in" by the artist (Groensteen, 2007, p. 28). Figure 5.8 illustrates the process so far.

3. Complete the drawings that go with the text. Braiding is the term used that establishes the sequence of pictures drawn for a comic (Groensteen, 2007). This sequence supports an overall narrative thread and at a glance reveals a visual structure. When illustrating the programming logic braiding is realised with the drawing sequence. As a narrative in computer science is different to a linguistic narrative, the images are actual representations of the transformation of data into visual information. I represented programming logic through the braiding. Figure 5.9 to Figure 5.13 have been included to give some examples of braiding and visual programming layouts. In the first milestone (see Figure 5.9), there was not much opportunity to have a consistent panel style across the pages for panelling. However concepts began to repeat after the first milestone. As such, each page represented a unique layout specific to what needed to be conveyed. For example, in Figure 5.9 an entire page was chosen to represent the core memory to show the sheer size of the hardware involved.

4. Input the layouts into the computer software (Illustrator).

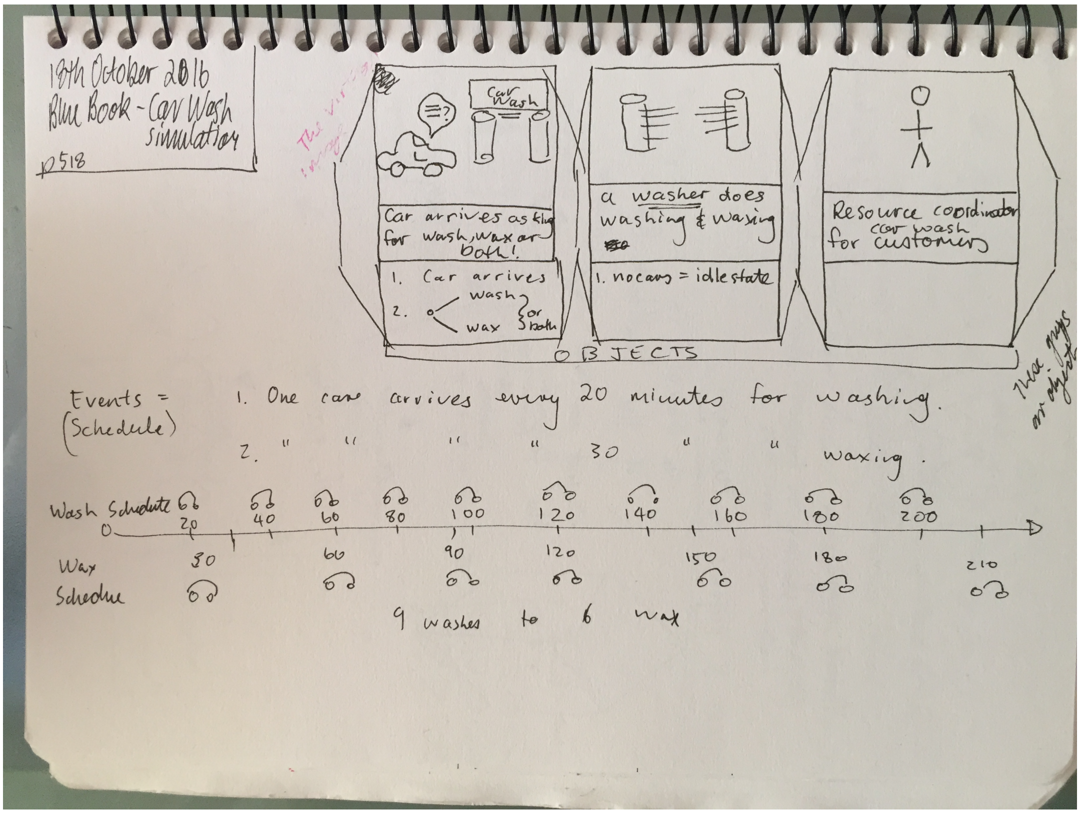

FIGURE 5.8: Sketching process in thesis

The above processes resulted in the outcomes addressed in the Section 5.12. The quantitative data analysis occurred within Research Phase Two and this is the next section discussed in the methodology.

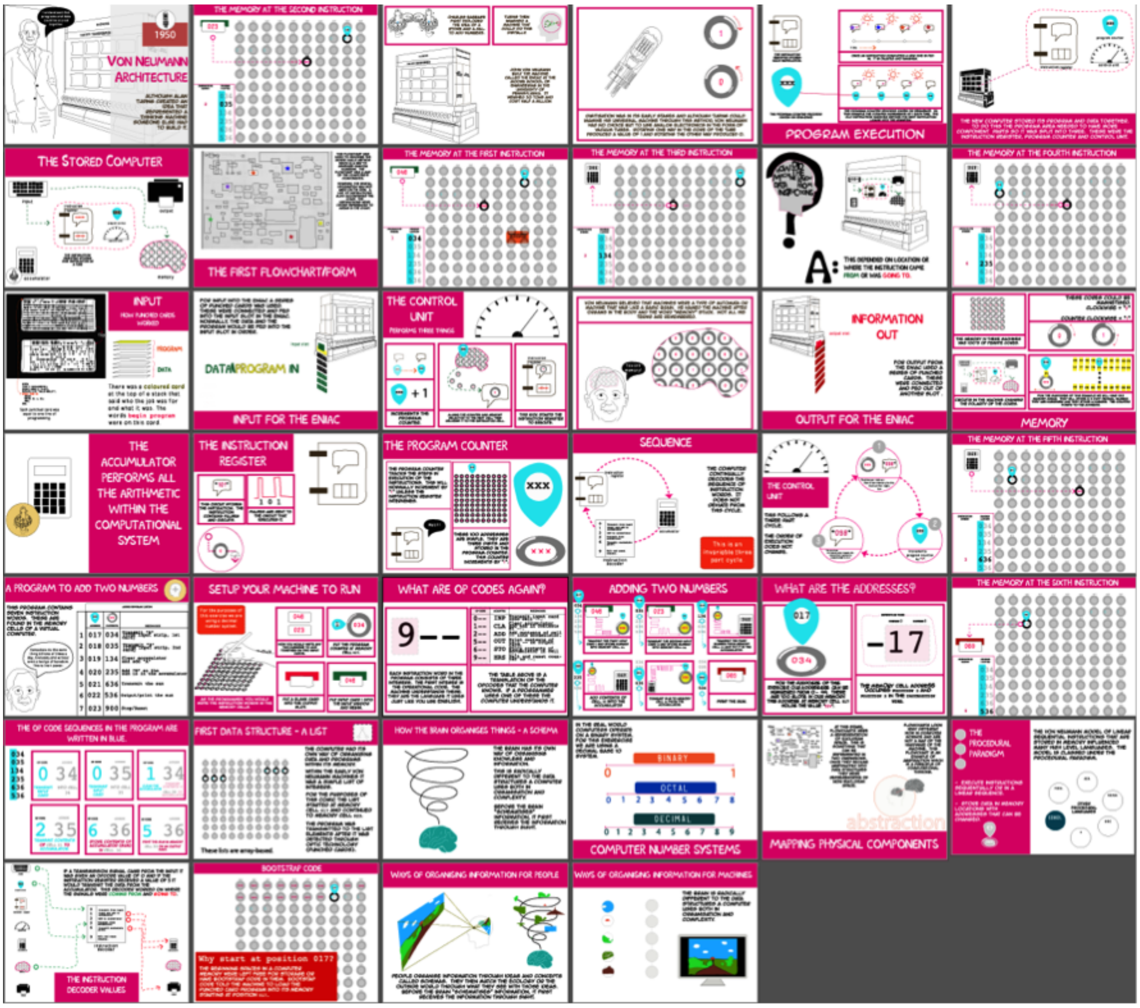

FIGURE 5.9: Page layouts of 1950s milestone

FIGURE 5.10: Excerpt on a non-programmable procedure, Tarr, 2017

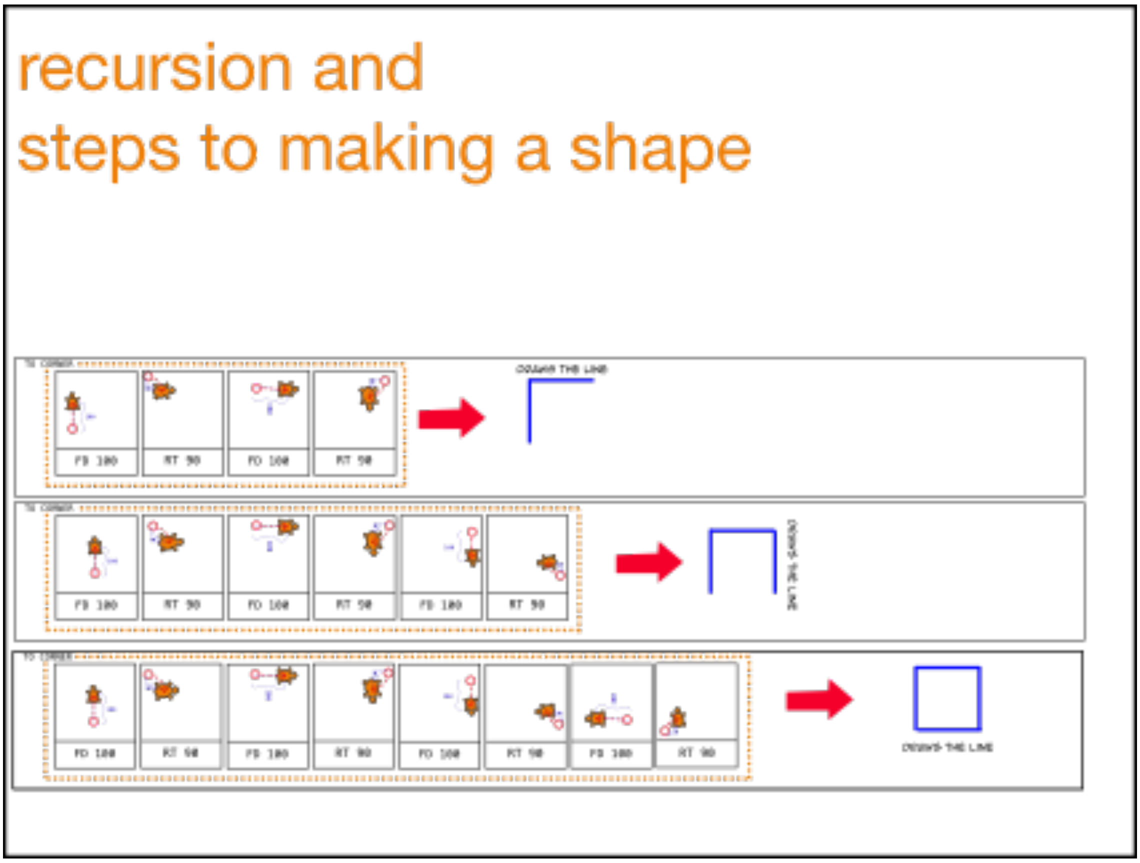

FIGURE 5.11: Braiding is aligned with the picture on the GUI, Tarr (2017)

Figure 5.11 is an example of using braiding in sequence to illustrate how the shape after the red arrow appears. The square shape appears by adding two panels into each row of sequences. The movements of the yellow turtle in each panel are represented by the blue path positioned to the right side of the red arrow.

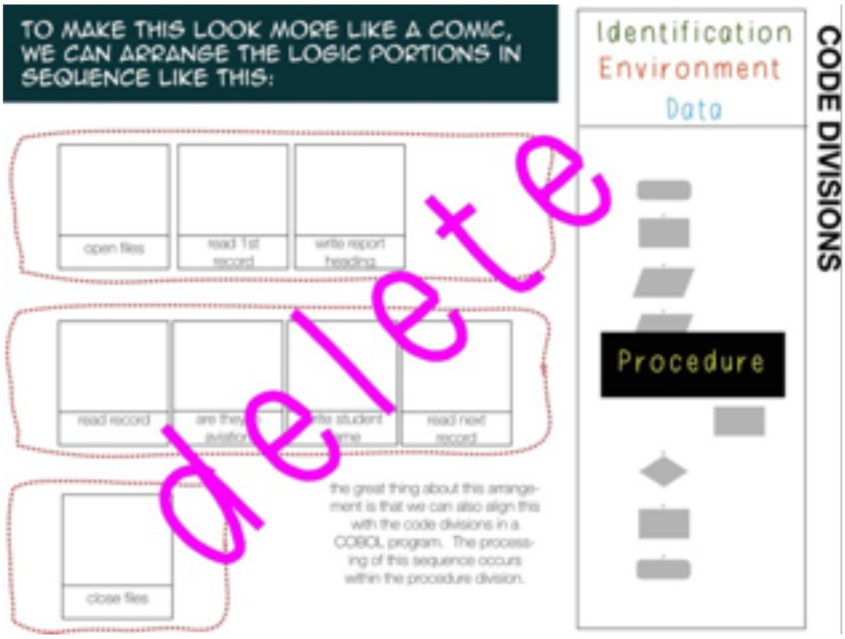

FIGURE 5.12: Braiding attempt to represent the flow chart, Tarr (2017)

Although Figure 5.12 was not included in the final version of the 1970s milestone, I attempted to represent a vertical flow diagram on the right with the horizontal sequences on the left. The braiding is absent in Figure 5.12 because I had not decided on the pictures to go in the panels. I had not yet found a visual metaphor for the programming logic.

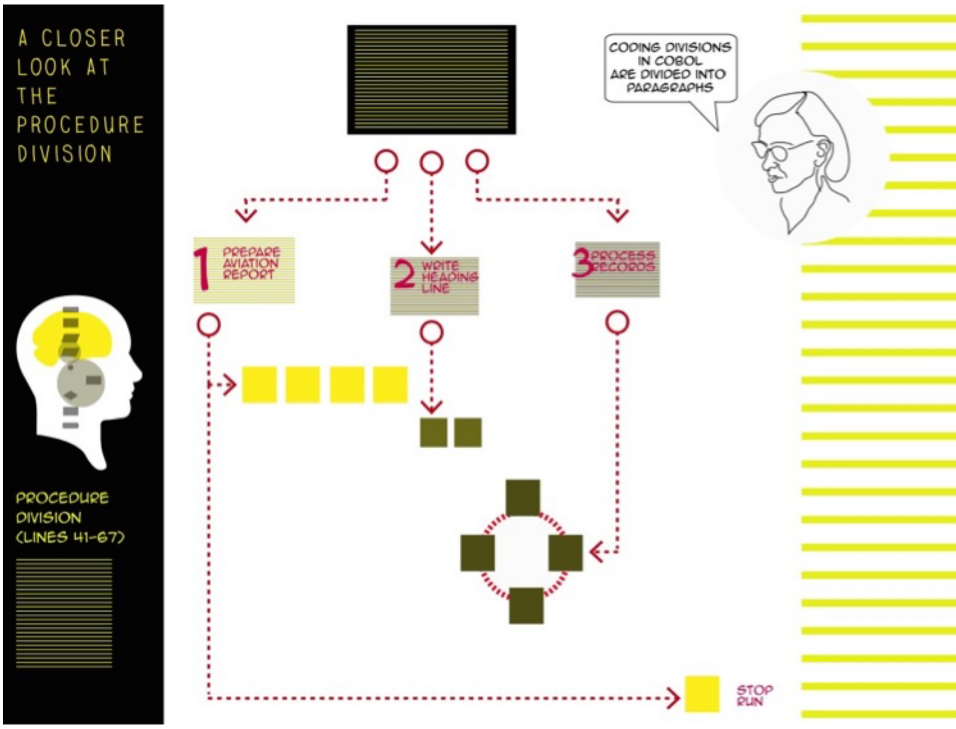

FIGURE 5.13: Braiding is linear and cyclical, Tarr (2017)

Within Figure 5.13 the programming concepts sequence, selection and iteration are revisited (see Figure 4.40). A layout for the concept of sequence is the coloured boxes under numbers "1" and "2". The dotted line under number "1" represents selection, as the program can progress along the yellow squares or end at the "stop" square in the right corner. A layout for the iteration concept is under number "3", with the four cyclical squares. Braiding is absent in Figure 5.13 as the pictures are absent in the yellow, green and dark green panels.

5.11 Reflections on the process of drawing within development of the milestones

The procedure to develop the milestones for TOAOCP was strengthened from the data gathered through the questionnaires and through the feedback during the focus group discussion sessions. In order to understand exactly how coding operates within a computer system, I drew the execution of the software step-wise on the page. I placed picture and code (sometimes I even included an interim level of pseudocode) within the same page space. The pictures in TOAOCP, often visual metaphors tying the relatively abstract computing concepts to objects in the physical world, were understood by the learners. Then through this understanding, the code was matched to any changes in the picture within the comic panel, to the previous picture's code within the preceding comic panel. This step-wise execution enabled different levels of realism to be represented within the same space on a page, and in this case the page space was a comic panel. The comic panel (see Chapter 4, Figure 4.22) is significant because it holds two pictures within the same space. The reason why different levels of realism should be represented within the same space on a page, is because relationships can be shown between the different types of pictures as in the Figure 5.14 to Figure 5.17.

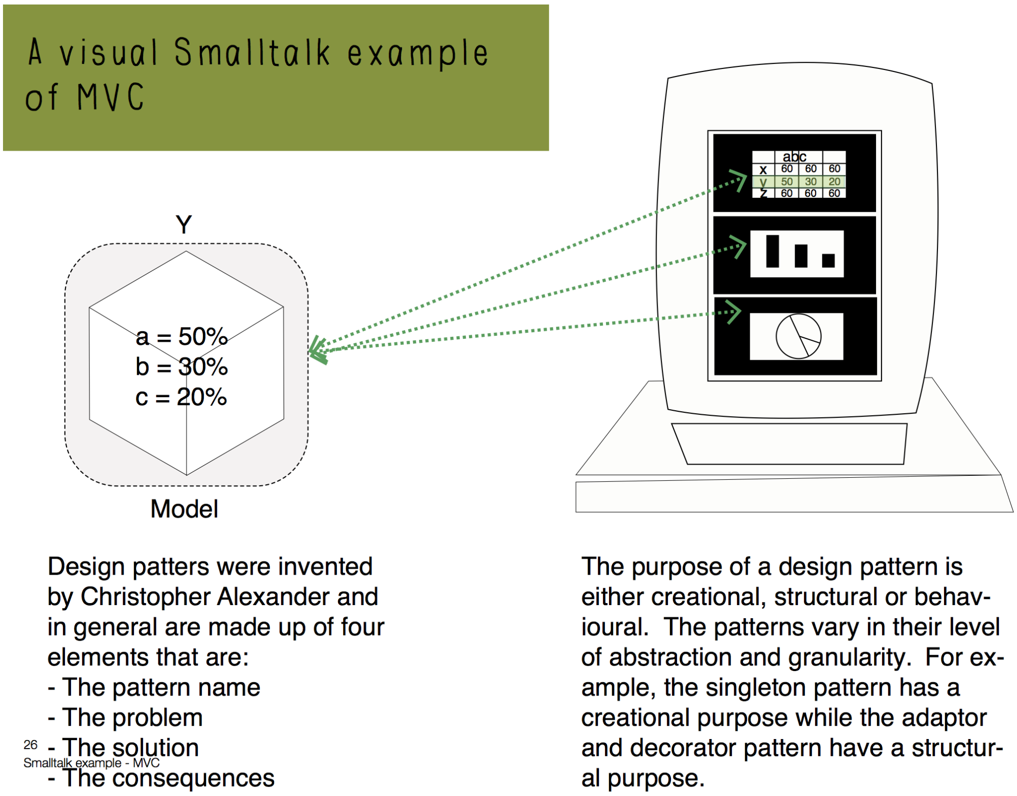

FIGURE 5.14: Different levels of realism in milestone four - MVC is introduced

In Figure 5.14 the software design pattern - model view controller (MVC) is introduced. During this time in the 1960s when Smalltalk was initially being used, design patterns such as MVC began to emerge. These patterns helped software developers to manage the complexity of programming. Within TOAOCP, pictograms see Figure 5.15 are used to represent MVC and then reused in the rest of the milestones. Multiple concepts can be represented within the same space by using different types of pictures.

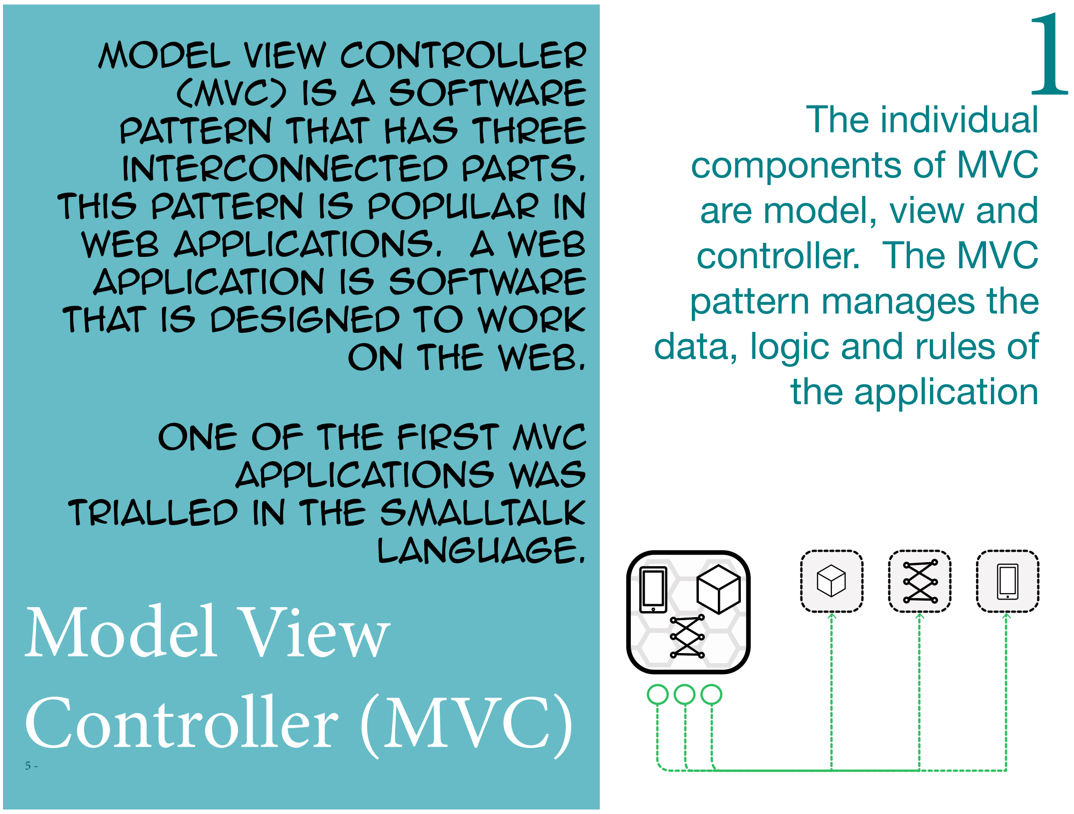

FIGURE 5.15: The model view controller (MVC) software design pattern is used again in milestone five

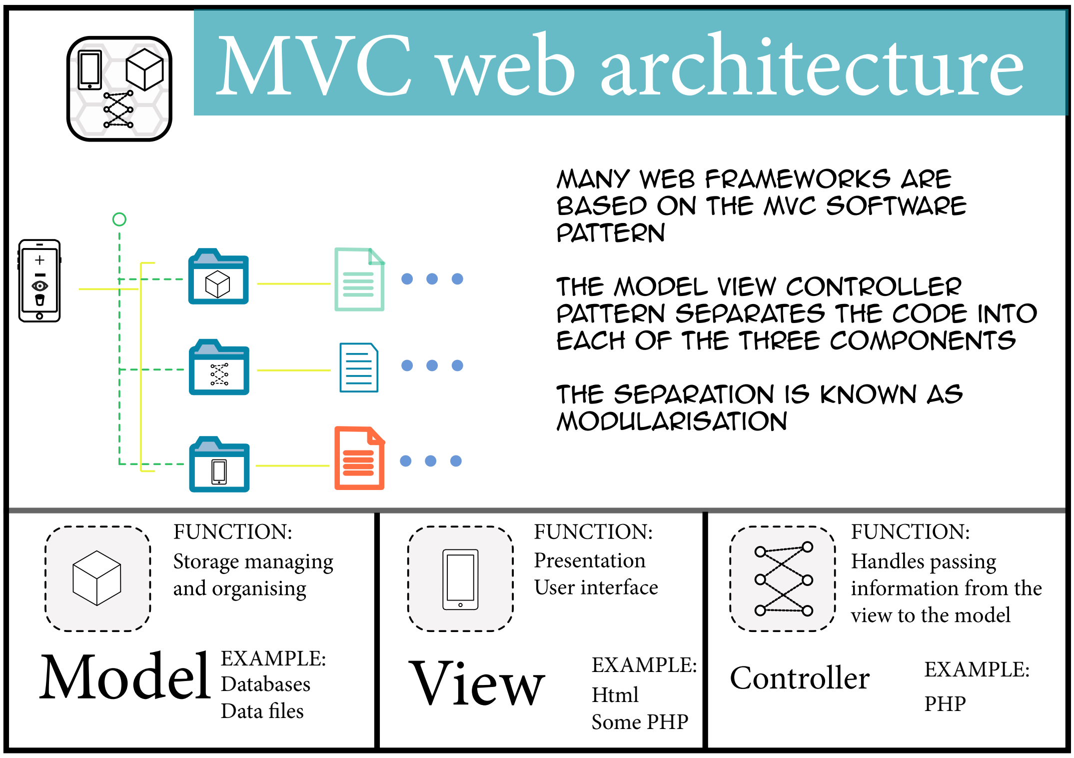

FIGURE 5.16: Different levels of realism in milestone five

Figure 5.17 represents the object model that is a mini contained within a hexagon. Directly under the hexagon, is the location of where the programming located within the interface. The coded listing or the function contained within the green polygon is the code that must be typed into the file *TransportListTableViewController.swift*.

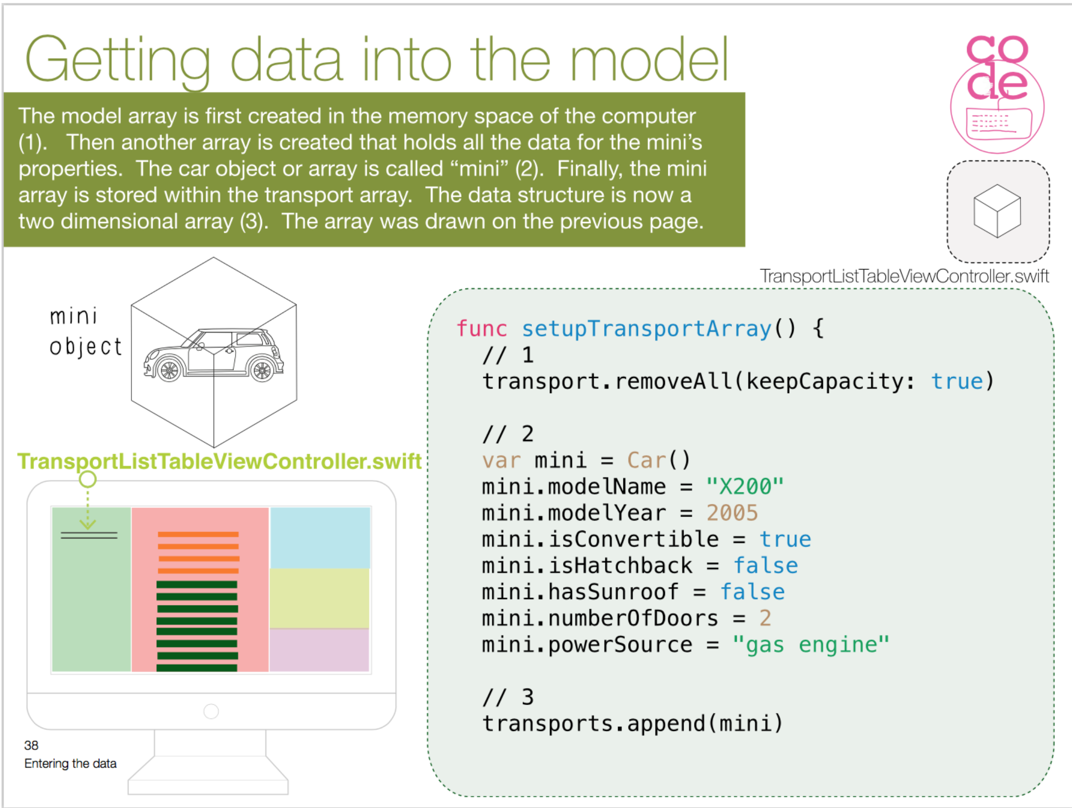

FIGURE 5.17: Different levels of realism in milestone six

In addition to this, more information can be represented in the same space. The milestones tested graphic design theories. Programming concepts that were difficult for participants to understand, such as binary tree traversal and computer geometry, were measured through the knowledge test in the quantitative questionnaire (see Chapter 6, Section 6.19). These concepts were further broken down from a higher to lower abstraction. When a layout was described as messy in the focus group sessions, the layout of the page was redesigned. For example, "messy" was the participant's terminology for wanting the steps on a page to be more ordered. Some of the pages were redesigned to experiment with clarity for students. In Chapter 4, Figure 4.29 the array or data structure could have been drawn once and then the arrows could be numbered next to the single array to reflect each line of code in a sorting procedure. The bubble sort procedure was done the way it is in the Chapter 4, Figure 4.29 because I was conscious of making the steps as clear as I could, so I drew each step (line of code) out individually for the sake of clarity. Visual literacy in the participants of TOAOCP was lacking, so with the bubble sort, I attempted to make the pictures and steps as clear as possible and progress sequentially through each line of code, as opposed to topologically representing the information in layers through differing levels of realism.

Drawing as a method of thinking now has a place within research methodologies. Sketching is essential in the preliminary stages and throughout the design process across a myriad of disciplines (Kare, 2014, 3:43). Noted designers carry and make use of their sketchbooks through drawing (Barry, 2016; Blaiklock, n.d.; Borson, 2011; Brownlee, 2016; Huang, 2008; Kim et al., 2009; Perry & Sanderson, 1998; Rose & Hardie, 2006; Schenk, 2015; Tovey et al., 2003; Van der Lugt, 2005).

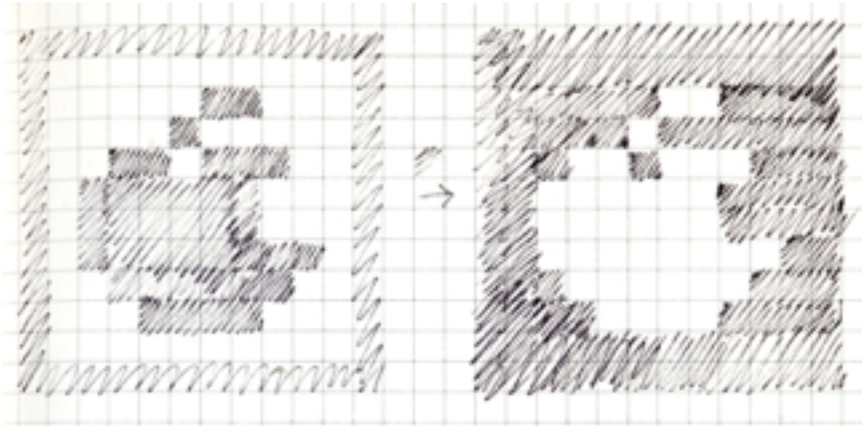

FIGURE 5.18: Apple sketch, Kare (1983), permission to use figure

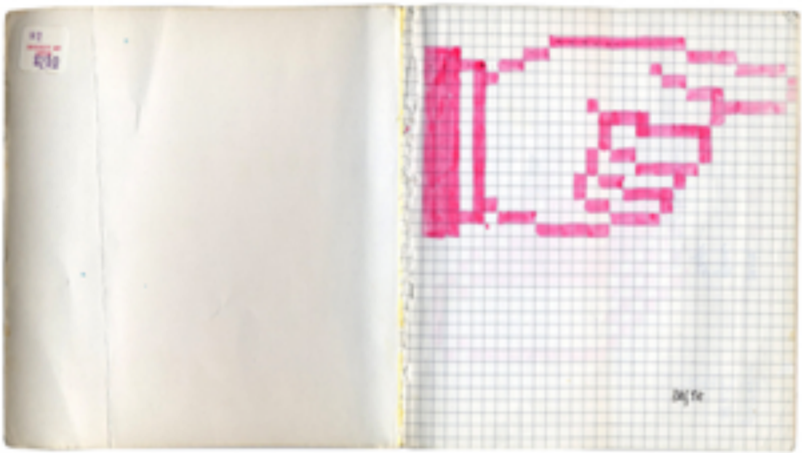

FIGURE 5.19: Initial sketch of a cursor, Kare (1983), permisssion ot use figure

Kare keeps a sketchbook of all her designs and Figure 5.18 is her drawing used as the idea for the Macintosh icon (Kare, 1983a). These books document a visual history of her thought processes. Figure 5.19 is a sketch of the cursor still clearly recognisable today, thirty years later (Kare, 1983b). The designs are not only static logos but also ideas such as the paper prototype in Figure 5.20. This picture (Figure 5.20) was a prototype for some icon editing software that Kare completed for an engineer. Graphic designers often plan and ideate concepts with pencil and paper. The drawing process has been an essential tool for the most successful designers in the documentation of thought. Kare (2011) also agrees that drawing designs and mapping the thought process of prototyping is invention. The importance of paper prototyping is often not stated (Kare, 2011; De Almeida, 2009; Poggenpohl, 1998). Within TOAOCP the instrumentation was treated as a prototype and the impacts were measured and recorded (see Chapter 6).

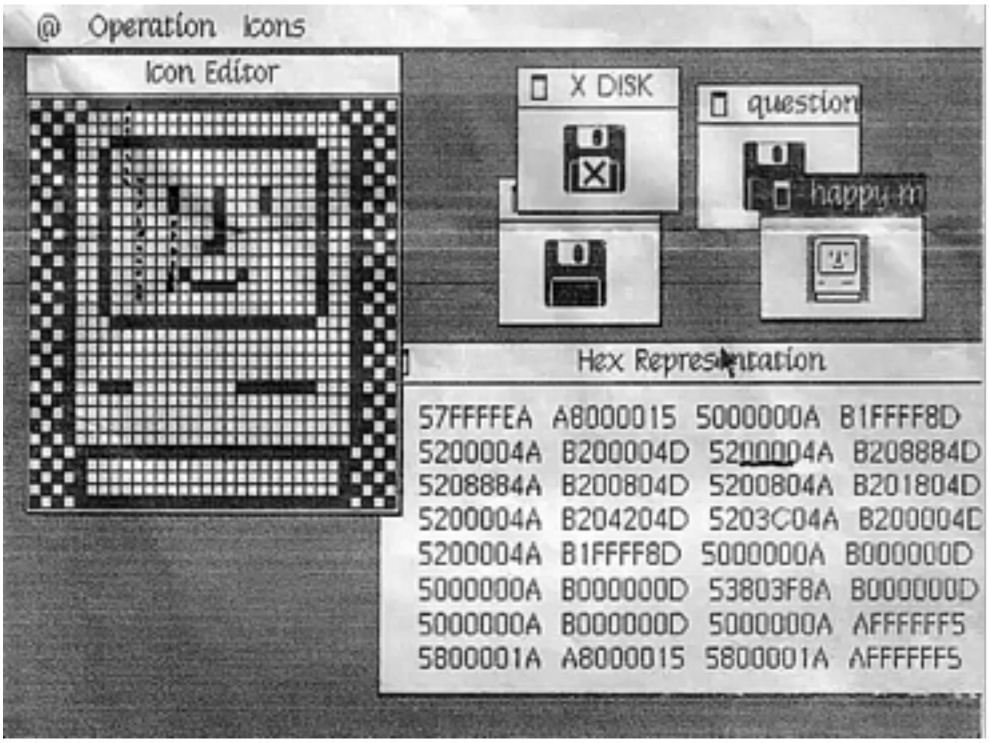

FIGURE 5.20: Paper prototype of an icon editor, Kare, permission to use figure

I will now outline the process of creating the milestones within the design process of TOAOCP. This outline is to explore the connection between sketching and understanding that was found in Chapter 6, Section 6.2.1 in the data collection from the participants. Through a process of deconstructive sketching, where the meaning of the code was hand drawn first, the intial draft was generated. Sketches of these milestones occurred during the intial design process of TOAOCP. When I drafted the lessons first through a sketch, the design flowed easier than digitally designing the lesson. When a lesson was entered straight into the graphic software, the process would take twice as long and end up failing. The lesson failed because the meaning-making was not clear within the lesson and the braiding (see Chapter 5, Section 5.10), did not make sense. As Holmes states, "'Drawing' with a computer is a very unnatural process. . . " (Berglund & Grimheden, 2011). I feel that sense-making accelerates when an individual's brain visualises a picture and the hand translates it by drawing. Drawing a design straight into the computer dulled the execution of the final artefact.

Figure 5.21 to Figure 5.23 are draft layouts of pages in a programming lesson made to produce the learning comic. The process was far more precise and less time consuming when I used a notebook first. Approximately 200 pages of comics illustrating programming concepts were hand-illustrated for the practical component of the thesis. Evident design elements emerged during this process such as sequence, selection and hierarchy as well as rhetorical characteristics. These characteristics or meaning making features in TOAOCP were the pictures combined with the code and arranged within panels. The design elements drawn in the sketchbooks were picture, sequence and hierarchy. By using these three elements, I developed the complex concepts for TOAOCP.

FIGURE 5.21: Pascal lesson organisation

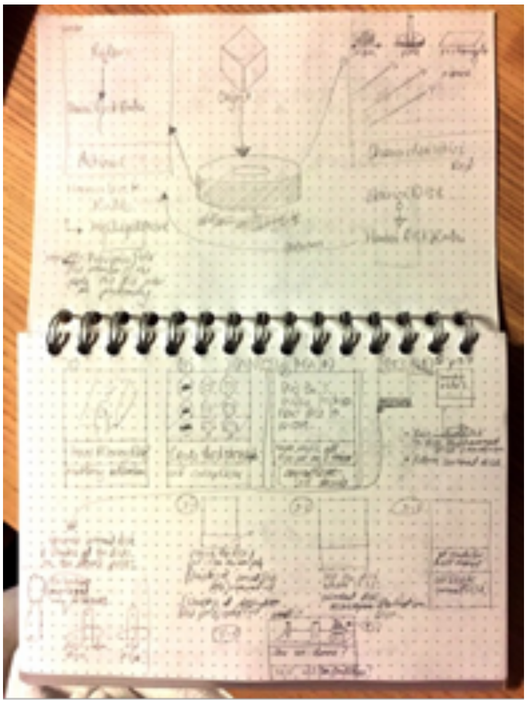

FIGURE 5.22: Initial design for towers of Hanoi lesson in Smalltalk

FIGURE 5.23: Draft concept to explain inheritance

Because complexity can be communicated through pictures, the thoughts of inventors can be understood through their drawings. For example, the Babbage diagrams stored at the Museum of Science in London enabled a rebuild of the Difference Engine II one hundred years later (see Figure 4.55). The documenting and recording of computer history is a wicked problem for computer historians (Connell, 2006). Perhaps it is the low picture agency within the computing texts that is the cause of the communication problem. If any of the research in TOAOCP is going to impact current learning practice, I hope it encourages a picture focused approach to education.

5.12 Outcomes

The following outcomes resulted from the study TOAOCP:

- 200+ page model visual curriculum that is in addition to the instrumentation (see Appendix A);
- Thesis;
- Posters (see Figure 5.24).

The visual curriculum comprises of the six files listed in Appendix A labelled as milestones from one to six. These are the picture-based work resulting from the research conducted during TOAOCP. These milestones document some of the major events that occurred in the history of computer science from 1950 onwards. The teachers voted upon what these milestones were to be.

The posters are artefacts containing narrative prompts that reflect the results in the focus group discussion relating to story. The historical reasons of why computing events and inventions occur increased the student's interest in learning programming. These posters (see Figure 5.24) would help a teacher as they would serve as narrative prompts to recount historical computing stories within a programming lesson.

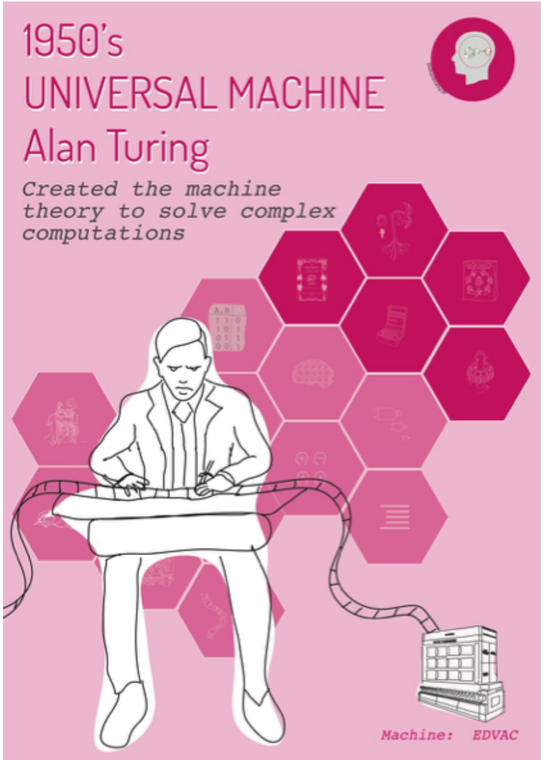

FIGURE 5.24: Poster from 1950s milestone

5.13 Ethics approval

Ethics was approved by both Edith Cowan University (ECU) and the Western Australia Department of Education (DoE) (see Appendix G). The students were between the ages of twelve and fourteen, so consent was required from the primary caregiver of the child, as well as the child. The student approval form from the DoE was for lower secondary school. Each school required approval from the principal, Information Technology (IT) director and each IT teacher. Ethics was granted from the 30th November 2017 to 31st January 2018 from the DoE and ECU to finish the thesis. According to the WA DoE guidelines, the following criteria must be satisfied by external parties conducting research:

- Include written approval from Central Office in the package of information provided to site managers when seeking their agreement to participate in a research project;
- Obtain informed written consent from the site manager for research to occur on the site, or for participants to be sought through the site (The site manager refers to the school principal and information technology director);
- Obtain informed, written, voluntary consent from all participants, except where in exceptional cases only, active recorded consent in a form other than written can be justified;

- Fully disclose to all participants and primary caregivers all information relating to the study in a manner that can be easily understood, including details of what participation will involve, any proposed audio or video recording, and any use of student work or data; and
- Obtain informed written consent from a primary caregiver and the research participant if the participant is under the age of 18 years. Informed consent from a primary caregiver must indicate that he or she has discussed the matter with their child, who in turn has agreed to participate.

(DoE, 2012, 3)

The letters and consent forms in Appendix G reflect the above guidelines.

This concludes the methodology section for the thesis for both quantitative and qualitative methods of data collection.

Chapter 6

Results

As the methodology followed an order outlined by Creswell (2014), the results section is structured to reflect his definition of explanatory sequential design. Creswell's methodology model of quantitative followed by qualitative research is an established method of conducting academic research. Alongside the quantitative and qualitative research methods that were being used, a set of learning comics was produced to reflect the findings. A practice-led component was also required to accompany the qualitative and quantitative methods within this study. According to Crouch:

> To theorize is not something that is done separately from doing; theorizing about something is thinking about how things are done . . . the two are intertwined. (Crouch & Pearce, 2013, p. 39)

The results section starts with the constructs, or factors that emerged from the quantitative analysis (see Section 6.1), the evidence these provide within the qualitative component (see Section 6.3), and finally their incorporation into praxis. The section begins with a quantitative analysis of the picture factors and is followed by the comics factors. By the requirements of quantitative analysis, the descriptive statistics will first be discussed followed by the preliminary data analysis.

6.1 Quantitative analysis

6.1.1 Sample descriptive statistics

Out of 97 samples collected from the participants, 59 usable responses were collected, this brought the final rate of response to 60 %. According to Baruch and Holtom (2008) this is satisfactory for a survey-based study. In six-months starting at July 2016 the data were collected. Descriptions of the responses are shown in Table 6.1. Detailed descriptive statistics concerning each factor are listed in Appendix C - Descriptive statistics.

TABLE 6.1: Descriptive statistics breakdown by gender and age

	Total
Male	21
Female	38
Total	**59**
12	3
13	51
14	5
Total	**59**

6.1.2 Preliminary data analysis

Treatment of missing values
Karanja et al. (2013) use a 20% cut-off point for their missing values. In accordance with this, 89 cases were included in the analysis. After this step, I used expected maximisation to impute the missing values. Results showed a missing value pattern of missing completely at random (MCAR). This MCAR value was supported by Little's non-significant MCAR test (x^2 = 179.487, df = 153, p = .070) and (x^2 = 140.081, df = 122, p = .126). The evaluation section of the questionnaire had a significant Little's test (x^2 = 418.990, df = 353, p = .009). According to Schafer and Graham (2002) missing at random (MAR) analysis methods using data that is not missing at random (MNAR) is still adequate or good. Data for the evaluation of the learning comic may not be as reliable as those values that measure attitudes toward learning comics. The imputed values derived from expected maximisation could be used in the rest of the analyses. None of the variables had data missing higher than 14.6%.

Expected maximisation (EM) is the technique used in TOAOCP to calculate and substitute values for those missing, and it was therefore in the methodology in Section 5.9.1. Univariate means consisting of one variable and refers to situations where one variable is measured. The univariate statistics were checked for the percentage of data for each missing value. Hair et al. (2006) set the missing value upper limit to 20%. If the missing value upper limit is more than 20%, then the missing data can bias the final result. The percentage of missing data did not rise above 7.1 %, therefore Little's test is satisfied and the data is missing completely at random (MCAR). The p-value is non-significant ($p > .05$). Here the data set pattern of missing values is random. I therefore used the imputed values derived from EM for subsequent analyses.

Data distribution test
According to the Shapiro-Wilk (SW) and Kolmogorov-Smirnov (KS) test, p-value < .05, at the univariate level the data violates an assumption of normality. Data that was non-normal or that was significant for SW and KS are listed in the following Table 6.2.

TABLE 6.2: Tests of normality

	Kolmogorov-Smirnov			Shapiro-Wilk		
	Statistic	**df**	**Sig.**	**Statistic**	**Df**	**Sig.**
Factor1Pictures	.091	59	.200*	.967	59	.115
Factor2Pictures	.134	59	.010	.958	59	.041
Factor3Pictures	.196	59	.000	.892	59	.000
Factor4Pictures	.087	59	.200*	.968	59	.129
Factor5Pictures	.081	59	.200*	.968	59	.119
Factor6Pictures	.114	59	.055	.975	59	.258
Factor7Pictures	.112	59	.061	.942	59	.007
Factor8Pictures	.150	59	.002	.928	59	.002

As discussed in Chapter 4, Section 4.5.3, the constructs or latent variables were established through adaption of a previous study (see Appendix B). The values for the latent variables Factor 2 Pictures, Factor 3 Pictures and Factor 8 Pictures, D(59) = .134, .196 and .150; $p < .05$, $p < .05$ and $p < .05$ were significantly non-normal. Shapiro-Wilk test also confirms non-normal data $p > .05$. According to (Pallant, 2010) although data can convert to normal distribution, the procedure results in sophisticated interpretations of statistics. Because of the non-normality of the data, non-parametric testing was used to calculate the statistics. The histograms of the variables were also assessed before the decision was made to use non-parametric tests for the rest of the statistical calculations. The next step in the preliminary data analysis was to check the bias of the data collection instrumentation.

Common method bias

Common method bias (CMB) measures error that threatens the validity of factors. A conclusion is based on statistical results and if these results are not valid, then the outcome of a finding is questionable. Validity is explicitly defined as:

> Evidence that a study allows correct inferences about the question it was aimed to answer or that a test measures what it set out to measure conceptually. (Field, 2013b, p. 795)

The presence of CMB was checked with Harman's single-factor score technique. As has been defined and discussed previously in Section 6.1.2, in Harman's technique, the manifest variables are fixed within the one common factor and a single factor rotation is performed on all the items. With a single factor rotation, all items were loaded into a single factor, and then a principle component analysis is run (PCA) as discussed earlier in detail (see Section 6.1.2). The principal axis factoring solution was un-rotated (Doty & Glick, 1998) and the result was not more than 50% of the variance RN1899, RN1905, with the percentage of variance being 32.126. As discussed in the methodology, an unrotated single factor exercise is performed so that if a common factor emerges, this would indicate that a CMB is present see Section 6.1.2. An example of a biased instrumentation is an uncalibrated bathroom scale that sits on one kilogram instead of zero when no one is standing upon it.

6.1.3 Attitudes toward pictures and comics

Results of the pretest (t0) show that students were positive towards pictures for the learning of computer programming. Mean scores larger than 3.00 are interpreted as positive, scores at 3.00 are neutral and lower than 3.00 are negative. On average the students anticipated they would have fun (M = 3.83, SD = .88) and that they would have the ability to use pictures easily (M = 3.48, SD = .99). They assumed pictures would be simple for them to use (M=3.69, SD = .745). There was little fear about using the pictures to learn to program with (M = 2.93, SD = .99). The results values for the items for fear are reverse scored so that a mean under 3.00 is good. Table 6.3 summarises the student's attitudes toward learning programming with pictures (t0).

TABLE 6.3: Attitudes toward learning to program with pictures (t0)

Variable	Item	M	SD	N
Usefulness (three items, a=.542)	"When learning with pictures, I will probably understand it better."	3.92	.822	58
	"I learn better with pictures."	3.71	1.3	58
	"I learn facts faster with pictures."	3.78	.99	58
Simplicity (three items, a=.663)	"Learning with pictures would be easy for me."	3.86	.825	58
	"I would be good at learning with pictures."	3.93	.90	58
	"It would be easy for me to learn computer programming with pictures."	3.3	1.16	58
Fun/Enjoyment (three items, a=.783)	"Learning with pictures is fun."	3.80	1.05	58
	"Learning with pictures makes the lesson more interesting."	3.66	1.2	58
	"I like learning with pictures."	4.02	.91	58
Personal Ability (three items, a=.850)	"I would be able to learn with pictures even if nobody was helping me."	3.53	1.15	58
	"Given time I can work out pictures without instructions to help me."	3.60	1.24	58
	"I know enough about pictures to study on my own."	3.32	1.16	58
Fear (three items, a=.804)	"I'm afraid I will not understand the pictures in the lesson"	2.97	1.24	58

continued . . .

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Variable	Item	M	SD	N
	"I'm afraid I will misinterpret the pictures in the lesson."	2.95	1.16	58
	"I'm afraid I will make a mistake in the lesson because of the pictures."	2.90	1.15	58
Intent to Use (three items, a=.607)	"I expect to learn something about computer programming if I use pictures."	3.53	.94	58
	"If I experience a lesson on computer programming in the next few months, I think I will learn something."	3.57	1.01	58
	"I want to use pictures more often when I learn computer programming."	3.57	1.08	58

Attitudes toward learning programming through a comic were also positive (t0). These attitudes are listed in Table 6.4. The students believed comics to be useful (M = 3.29, SD = 1.02) simple (M =3.17, SD = .89), fun (M =3.37, SD = 1.02) and they would have a strong ability (M =3.27, SD = .88) when learning to program with a comic. The students also generally expected to learn to program through the comic medium. There was neutral to a negative expectation of not understanding the comic (M = 2.99, SD = 1.17). Unfamiliarity with interpreting the meaning of the comic was the reason for the expectation. The next section examines the pre and posttest differences between the individual factors that form the Attitudes.

TABLE 6.4: Attitudes toward learning to program through a comic (t0)

Variable	Item	M	SD	N
Usefulness (three items, a=.878)	"I learn computer programming better with comics."	3.305	1.12	59
	"I learn computer facts faster with comics."	3.186	1.17	59
	"When learning with comics, I will probably understand computer programming better."	3.254	1.15	59
Simplicity (three items, a=.821)	"Learning computer programming with comics would be easy for me."	3.23	.975	59
	"I would be good at learning computer programming with comics."	3.3	.965	59
	"It would be easy for me to learn programming with comics."	2.98	1.15	59
Fun/Enjoyment (three items, a=.829)	"Learning computer programming with comics is fun."	3.25	1.20	59

continued ...

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Variable	Item	M	SD	N
	"Learning with comics makes the programming lesson more interesting."	3.39	1.20	59
	"I like learning computer programming with comics."	3.45	1.15	59
Personal Ability (three items, a=.821)	"I would be able to learn computer programming with comics even if nobody was helping me."	3.30	1.09	59
	"Given time I can work out computer programming without a comic about programming to help me."	3.27	1.03	59
	"I know enough about comics to use them to study computer programming on my own."	3.23	.99	59
Fear (three items, a=.798)	"I'm afraid I might break/rip the comic in the lesson"	2.89	1.42	59
	"I'm afraid I might turn to the wrong page in the lesson."	2.9	1.42	59
	"I'm afraid I will not understand the lesson."	.2	1.31	59
Intent to Use (three items, a=.870)	"I expect to learn something about programming in the future if I learn with comics."	3.30	1.16	59
	"I think I will learn something in the future about programming."	3.69	.15	59
	"I want to use comics more often when I learn computer programming."	3.25	1.30	59

Pre and posttest comparison of attitudes by factor

There was a change in the average scores of all Attitudes factors within the pre and posttests for pictures. However not all of these changes were significant. As the increased trends were established, I would expect that with more participants these shifts in the attitudes components would be significant. The following table lists the changes in the factors before and after the participants used the learning comic. The significance (*) was determined with a Wilcoxon test, that is the non-parametric equivalent to the paired T-test (see Section 5.9.1.2).

Although all picture factors and comic factors increased in the posttest (see Table 6.5), those that are significant can be seen in the following graphs (Figure 6.1 to Figure 6.3).

TABLE 6.5: Attitudes factors before and after treatment

Factor	Pretest	Posttest	Diff
Picture Usefulness	3.79367	3.8193	0.02563
Picture Simplicity	3.69467	3.757	0.06233
Picture FunEnjoyment	3.838	3.87	0.032
Picture Personal Ability	3.48567	3.5143	0.02863
Picture Fear	2.932	2.949	0.017
Picture Intent	3.559	3.738	0.179
*Comic Usefulness	3.2483	4.4817	1.2334
*Comic Simplicity	3.16967	3.39067	0.221
Comic FunEnjoyment	3.3673	3.40167	0.03437
*Comic Personal Ability	3.271	3.452	0.181
*Comic Fear	2.997	2.691	-0.306
Comic Intent	3.418	3.46167	0.04367

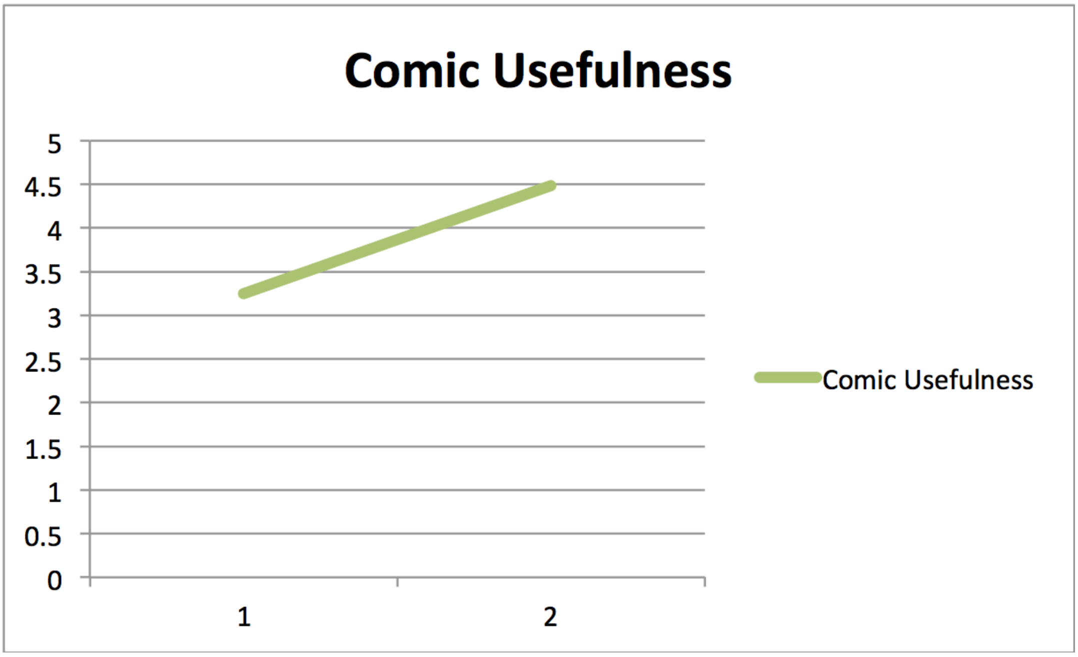

FIGURE 6.1: Comic Usefulness

Usefulness of learning programming through a comic significantly shifted after using the instrumentation. The participants learnt computer programming better with comics, as well as learning facts faster with comics, they also understood the programming better than before the treatment.

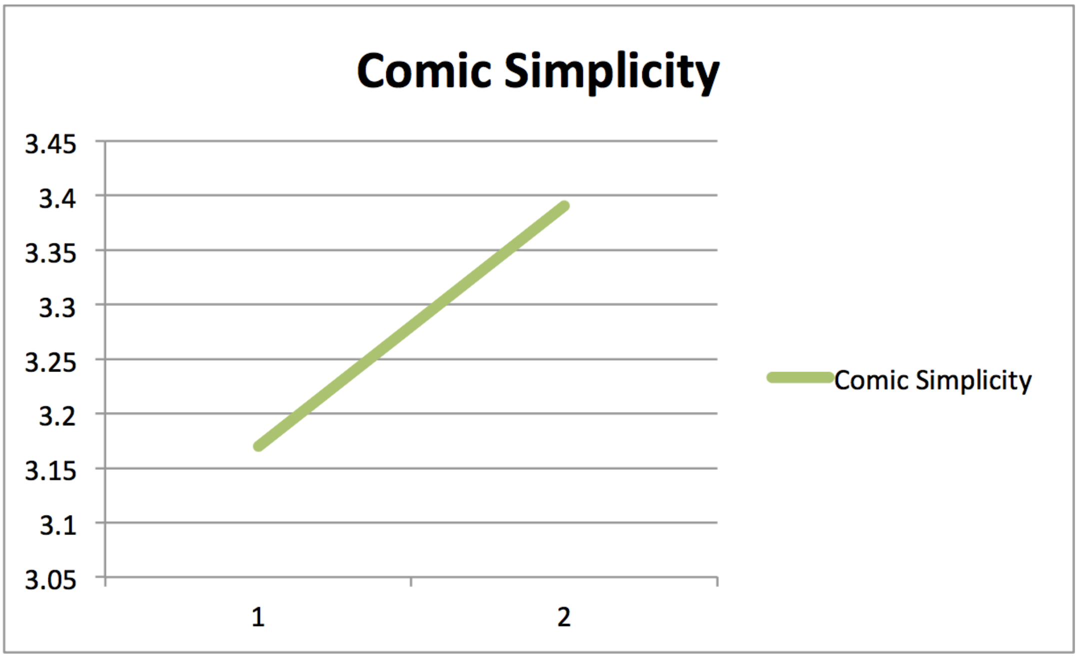

FIGURE 6.2: Comic Simplicity

Simplicity when learning programming through a comic was also significantly impacted in a positive way. Participants found that the learning comic simplified learning computer programming.

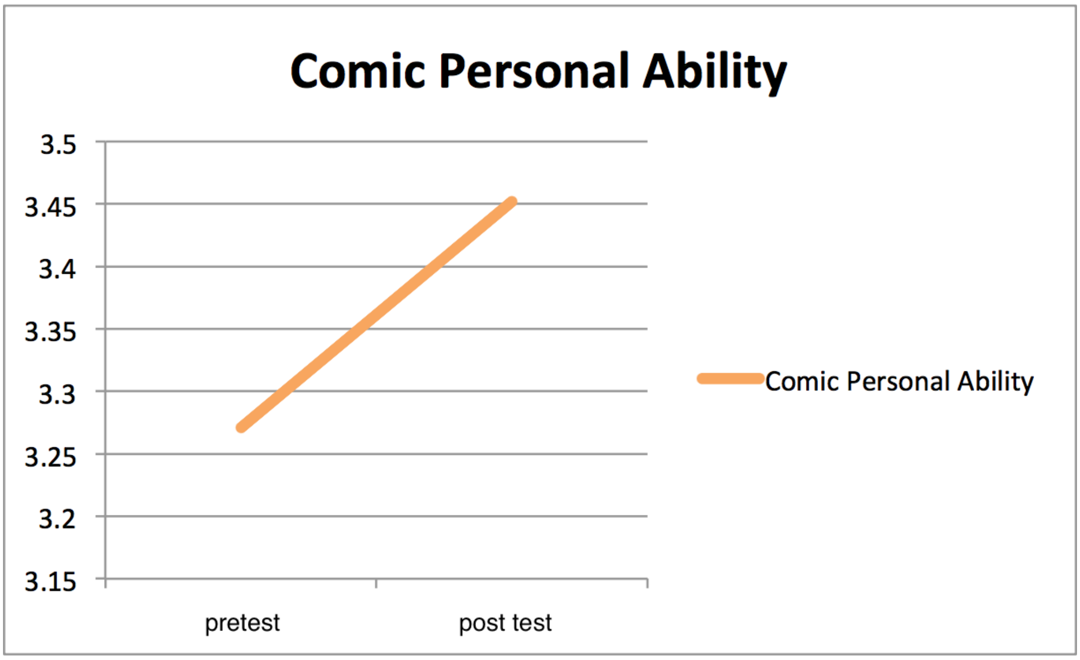

FIGURE 6.3: Comic Personal Ability

The Personal Ability of the participant's when learning computer programming through the comic significantly increased. Participants felt that they were better programmers after the intervention. Their Personal Ability concerning programming was impacted positively. Self-efficacy is defined as a person's personal belief in their own ability (Bandura, 1982). The participant's felt they had self-efficacy through their own skill set when it came to computer programming, and their confidence dramatically improved concerning their programming ability after using the learning comic. The participants were also less fearful about computer programming after using the learning comic, and the mean concerning the factor of Fear significantly decreased. In summary for the comparison of individual pre and posttest factors, the comic factors were all positively and significantly impacted except for Fun and Enjoyment. Although Fun and Enjoyment was still a salient factor when learning programming from a comic the participants prioritised other factors over Fun as it became clear the comic was a serious learning tool for the navigation of complexity.

Influence of Attitudes towards Intent to use pictures (t2)
Summary statistics or aggregates were used to gauge the impact of Attitudes upon the Intent for using pictures. Figure 6.4 represents a basic regression model that was used to explain the influence of Attitudes upon Intent to use a learning comic in the future to learn to program. Attitudes were found to be significant upon the Intent to learn computer programming throughout; additionally, Fun was a salient predictor of Intent.

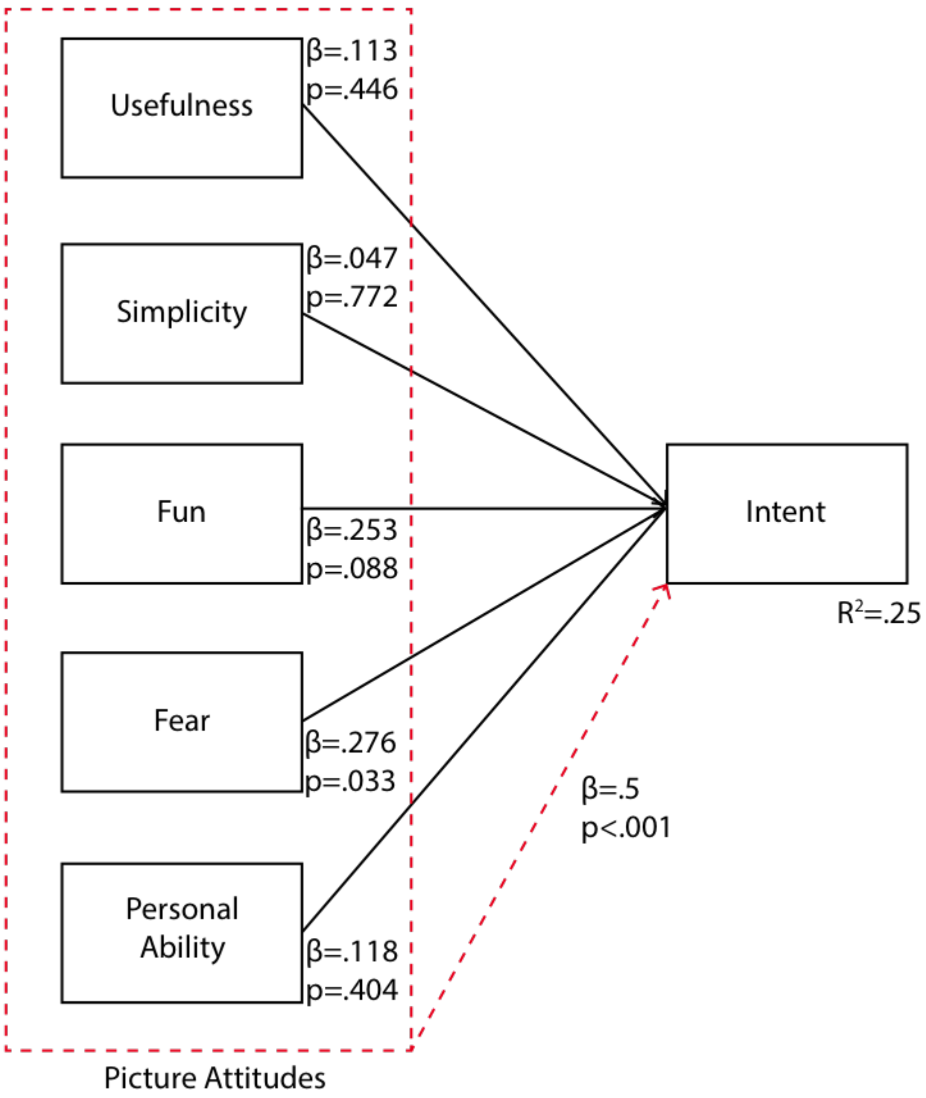

FIGURE 6.4: Picture Attitudes and their impacts on Intent

Influence of Attitudes towards Intent to use comics (t2)

A second aggregate model was constructed to gauge Attitudes towards comics and the Intent to use them (Figure 6.5).

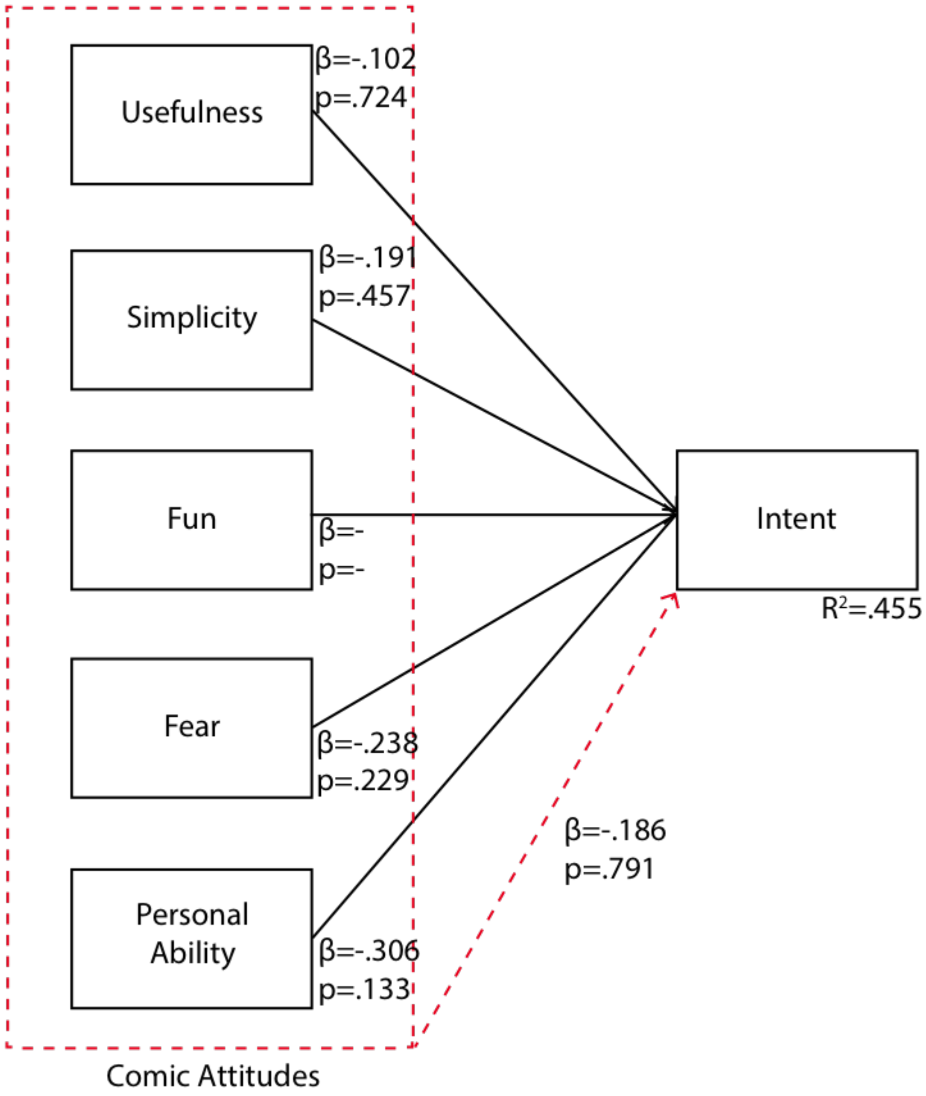

FIGURE 6.5: Comic Attitudes and their impacts upon Intent

At this stage of the analysis, like the preceding picture model, the comic model offered moderate significance for Attitudes upon Intent. In contrast to pictures, Fun as a factor when learning from comics was excluded by the software from the analysis. This was due to other variables receiving a higher value than Fun, and the factor was not thought by the participants to be significant when learning from a comic. Another interpretation would be that there was a high correlation between Fun and another variable. The result of Fun not loading in the exploratory factor analysis (EFA) supports the material in the literature review about information and anxiety (see Section 4.3.8). The existing modified technology acceptance model (TAM) did provide significance for Attitudes towards comics when the aggregate score for the Attitudes factor was calculated. A further EFA was needed to understand how Intent was affected by Attitude. This EFA would also help explain loadings on the factors, and confirm if they were valid. High correlations between the modified TAM variables could also be seen with the EFA. When the factor Fun was tested as the independent variable upon the dependent variable of Intent, the impact was high with a beta value of .625 and significant ($p<.001$, $R^2=.391$).

The linear regression model for the factor Fun and the impacts upon learning through a comic can be seen in Figure 6.6. Although highly significant, this factor failed to work with the rest of the model because of multicollinearity. Multicollinearity is when two variables are very closely linearly related. Fun was not a high loading factor when using a comic to learn to program, since other factors showed as having priority over Fun when learning in this way.

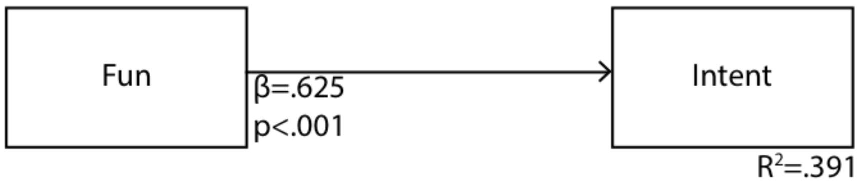

FIGURE 6.6: Individual factor of fun and intent to learn through a comic

TABLE 6.6: Summary table for attitudes of pictures and comics and their impacts upon intent (t0).

Picture intent α **=.816** **(three items)**	**Alpha**	**Beta**	ρ
Usefulness (three items)	.839	.113	.446
Simplicity (three items)	.880	.047	.772
Fun/Enjoyment (three items)	.796	.253	.088
Personal Ability (three items)	.834	.118	.404
Fear (three items)	.882	.276	.033
Attitudes (fifteen items)	-	.5	<.001
Comic intent α **=.776** **(three items)**	**Alpha**	**Beta**	ρ
Usefulness (three items)	.914	-.102	.724
Simplicity (three items)	.878 .	-.191	.457
Fun (three items)	.807	.625	<.001
Fear (three items)	.853	-.238	.229
Personal Ability (three items)	.766	-.306	.759
Attitudes (fifteen items)	-	1.214	.041 (<.05)

As the loadings of some of these scales may be dependent on more than one parent factor, exploratory factor analysis (EFA) was conducted upon the technology acceptance model (TAM) data to satisfy convergent validity. Convergent validity concerns each item and its loading upon a factor. The value of the validity should be over .50 so as to be considered valid. It is interesting to note that the participants thought the comic was Fun, when learning programming from a comic, when the Fun items are considered in isolation and aside from Usefulness and Simplicity. Usefulness and Simplicity turn out to be highly correlated with Fun in the EFA. The high correlation between the three factors of Fun, Usefulness and Simplicity could indicate the three factors all measure another underlying factor. Although this occurred with comics, it did not occur with pictures. A further Kruskal-Wallis test test was run to see if the factor of Intent for each design element differed significantly from school to school. There was however no significant difference found as seen in Table 6.7 and Table 6.8.

TABLE 6.7: Group comparison for picture intent

Ranks

	Group	**N**	**Mean Rank**
Post Picture Intent	1.00	12	26.63
	2.00	10	33.90
	3.00	6	37.67
	4.00	11	24.45
	5.00	7	32.07
	7.00	13	30.15
	Total	59	

Test Statistics Post Picture Intent Chi-Square 3.534
Df 5 Asymp. Sig. .618

TABLE 6.8: Group comparison for comic intent

Ranks

	Group	**N**	**Mean Rank**
Post Comic Intent	1.00	12	33.04
	2.00	10	27.40
	3.00	6	37.83
	4.00	11	27.23
	5.00	7	34.79
	7.00	13	25.35
	Total	59	

Test Statistics Post Comic Intent Chi-Square 3.724
Df 5 Asymp. Sig. .590

The Wilcoxon Signed Rank test is the non-parametric equivalent of the paired T-test. The test was used to compare pre and posttest items individually, and provides a measure of the effect of the treatment.

6.1.4 Wilcoxon Signed Rank test

Before the EFA was run, a Wilcoxon Signed Rank test was calculated on the items comparing the pre (t0) and posttest (t2) data. The descriptive statistics output from this test are listed in Appendix C - Descriptive statistics. The treatment was successful with participants significantly recording an increase in learning programming better with comics. Thinking how easy it would be to learn to program and their personal ability also increased. Participants believed that comics could help them learn computer programming on their own, and successfully after using the learning comic.

After the initial comparisons were made between pretest (t0) and posttest (t2) items, the analysis moved to the evaluation of the learning comic. The evaluation items (t3) were designed to measure cognitive, motivation and other self-assessed learning gains.

6.1.5 Evaluation of the learning comic and pictures

After the students had used the instrumentation, they evaluated the pictures within it positively. The Picture Clarity variable, or consideration they gave to looking at the pictures, was that they devoted time to understanding what the pictures meant (M=3.33, SD=.81). They also desired fast communication, that is, the participants wanted to recognise the pictures quickly. There was good confidence from the participants concerning how they felt they understood the pictures and the visual concepts (M=3.27, SD=.85). They also felt they learnt something new through them (M=3.5, SD=.95). The Picture Representation was also high, with the participants gaining new visual understanding of programming concepts (M=3.51, SD=1).

TABLE 6.9: Evaluation of the pictures in the instrumentation for TOAOCP

Variable	Item	M	SD	N
Picture Clarity	"During the lesson I spent time thinking about what the pictures were saying."	3.33	.81	59
	"During the lesson I did not care about what the pictures were communicating I just wanted to finish."			
	"I was only interested in learning from the pictures if they explained things the best way to me." (reverse item)			

continued . . .

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Variable	Item	M	SD	N
Picture Confidence	"When I learn from a picture I feel I learn the right way."	3.27	.85	59
	"When I learn visually, I'm learning the wrong way." (reverse item)			
	"When looking at the pictures, I understood the concepts."			
Picture Literacy	"The pictures explained things."	3.5	.95	59
	"I felt confident I learnt something new with the pictures."			
	"When looking at the pictures, I understood the concepts."			
Picture Representation	"The pictures explained things."	3.51	1.0	59
	"I felt confident I learnt something new with the pictures."			
	"The pictures revealed information to me."			

The learning comic was also evaluated by the participants. There are different design elements used within pictures and comics, so evaluation was made separately for pictures and comics. Students overall were not aware whether they were learning when using a comic despite believing that the comic explained things and that it had revealed new information. This may be because of an existing reliance upon mental models (as was previously established in the literature review of this thesis). Students scored good Comic control or Perceived behavioural control (PBC): They did not feel that using the learning comic was something out of their control (M=3.30, SD=.93) and they considered the Strategy and took time in using the comic (M=3.24, SD=94). Student's thought their friends and family would be positive about learning computer programming through a comic (M=3.21, SD=.87).

TABLE 6.10: Evaluation of the comic in the instrumentation for TOAOCP

Variable	Item	M	SD	N
Comic Confidence	"When I learn from a comic I feel I learn the right way."	2.97	.93	59
	"When I learn visually, I'm learning the wrong way."			
	"When looking at the comic I understood the concepts."			
Comic Cognition	"The comic explained things."	2.97	.93	59
	"I felt confident I learnt something new			

continued . . .

Variable	**Item**	M	**SD**	**N**
	with the comic." "When looking at the comic, I understood the concepts."			
Self-Assessed Cognition Comic	"The comic explained things." "I felt confident I learnt something with the comic." "The comic revealed information to me."	3.24	1.04	59
Comic Control	"Using this type of comic is entirely within my control." "I have the knowledge and ability to use these type of comics." "I am able to skillfully use this type of comic."	3.30	.93	59
Comic Strategy	"During the lesson I spent time thinking about what the comic was saying." "During the lesson I did not care about what the comic was communicating I just wanted to finish."	3.24	.94	59
Subjective Norm	"My friends would like if I learnt through this type of comic." "My parents would like if I learnt through this type of comic." "My family would like if I learnt through this type of comic."	3.21	.87	59

Four other measurements were taken concerning the overall cognition and motivational effect of using the learning comic. The generic measurements are listed in Table 6.11. These measurements did not contain wording that specifically referred to pictures or comics. Flow and Prior Knowledge were also assessed with no mention of pictures or comics. After, the treatment students believed that they had learnt something about programming (M=3.24, SD=.78). They were motivated (M=3.23, SD=1.04), and they indicated that they were in flow (M=3.18, SD=1.00). There was evidence that the students were also relying on existing knowledge that they had acquired about programming (M=3.18, SD=1.08). It is not clear whether this existing knowledge was prioritised over the new knowledge about programming or if new understandings were acquired from the learning comic.

TABLE 6.11: Evaluation items not specific to pictures and comics

Variable	Item	M	SD	N
Cognitive learning effect	"In the lesson I learnt about programming."	3.24	.78	59
	"In the lesson I learnt I should avoid programming."			
	"Because of this lesson I am more confident about programming."			
Motivational learning effect	"The lesson increased my interest in programming."	3.23	1.04	59
	"While in the lesson I would like to learn more about programming."			
	"Because of the lesson, I am more aware of programming concepts."			
Use of Prior Knowledge	"To complete the lesson it was important that you know a lot about programming."	3.18	1.08	59
	"To get through the lesson it was important that you know about programming."			
	"To get through the lesson I need to know more about programming."			
Flow	"In the lesson, I was thinking only about the learning from it."	3.18	1.00	59
	"In the lesson, I forgot things going on around me."			
	"In the lesson, time went quickly."			

The learning comic was evaluated positively by the participants, and the pretest (t0) and posttest (t2) comparisons indicated a general increase in positive attitudes toward the learning comic. Some linear regressions were run to test the impacts of enjoyment upon cognition and motivation and also upon the test scores. These tests were in keeping with the existing literature and other findings concerning enjoyment and learning from digital artefacts.

Influence of Fun and Enjoyment of pictures on cognitive learning gain
A linear regression was run on the Fun and Enjoyment of learning computer programming with pictures and on the Self-Assessed Cognition of learning computer programming with pictures. The effect on the independent variable that is Fun and Enjoyment when learning with pictures was found to affect the value of Self-Assessed Cognition substantially (β =.28). As Fun and Enjoyment increase so do the self-assessed learning gains (Self-Assessed Cognition). The more fun, the more perceived understanding there is. 8% of the total variance can be explained by the regression model ($F(1, 57) = 4.96$, p =.03).

Influence of Fun and Enjoyment of the pictures on motivational learning gain

A similar regression was conducted where the dependent variable was the Self-Assessed Motivation, instead of Self-Assessed Cognition. The regression was also found to be significant for Fun and Self-Assessed Motivation to learn to program using pictures (β =.36). This model explained 13% of the variance (F(1, 57) = 8.755, p=.005). As Fun in learning programming with pictures increases, so does the Self-Assessed Motivation to learn computer programming.

Influence on test score of the experience of Fun and Enjoyment of learning comics

There was no impact in using the actual test score as the dependent variable against Fun and Enjoyment. That is to say the Fun and Enjoyment experienced within the learning comic had no impact (β =-.12) on the test score. In fact, Prior Knowledge (β =-.371) was the only variable that had an impact on the actual test score (F(8, 50)=1.008, p=.033). There was a negative reliance upon existing knowledge of programming. Therefore this indicated that the introduction of a new visual artefact may actually conflict with existing mental models previously established by a participant about computer programming.

Influence of the Subjective Norm, Flow and Strategy upon Self-Assessed Cognition of the learning comic

The total variance for this model was 38%. F(3,55)= 11.4. Being in flow had a strong effect upon perceived cognition (β =-.26, p=.04). The Subjective Norm had a highly significant effect upon the factor of Self-Assessed Cognition. This would indicate that as the state of being in flow increases so does Self-Assessed Cognition. As reading the comic increasingly engages a person the Self-Assessed Cognition is increased significantly. It would seem that the very act of 'reading' a comic would contribute significantly to putting a person into a flow state.

Alignment with the theory of planned behaviour

During this stage of the analysis, another relationship emerged. The evaluation set of items contained a variable named Comic Control. This variable was adapted from a gaming questionnaire within another study Fu et al. (2009b); Iten and Petko (2014). This measure also contained items to partially calculate a two-factor construct called Perceived behavioural control (PBC). PBC measures both internal and external control when using a system or in this case a learning comic. There was a significant impact on intent by the computer control variable. In contrast, the Subjective Norm had no influence over the Intent to learn. This measure was taken from the posttest (t3) data and can be viewed in the following Tables 6.12 to 6.14.

TABLE 6.12: Model summary for TPB posttest (t2) comic data

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	.679	.461	.431	.78267

Predictors: (Constant), Comic Control, Comic Attitudes, Subjective Norm

TABLE 6.13: Anova data for TPB posttest (t2) comic data

Model		**Sum of Squares**	**df**	**Mean Square**	**F**	**Sig.**
1	Regression	28.793	3	9.598	15.668	.000
	Residual	33.691	55	.613		
	Total	62.484	58			

As the instrumentation was only a paper prototype, the second construct that makes up theory of planned behaviour could not be worked into the study. This construct concerns external control as well as resourcing, and could be quantified in a future study through the inclusion of a 'help' menu and the inclusion of a feedback capacity within the software.

TABLE 6.14: Coefficients table for TPB posttest (t2) comic data

		Unstandardized Coefficients		Standardized Coefficients		
Model		**B**	**Std. Error**	**Beta**	**T**	**Sig.**
1	(Constant)	.389	.492		.790	.433
	Comic Attitudes	.918	.178	.654	5.156	.000
	Subjective Norm	-.298	.179	-.249	-1.667	.101
	Comic Control	.317	.151	.286	2.103	.040

a. Dependent Variable: Comic Intent

6.1.6 Skill set and test score

Descriptive statistics were performed on the four types of skill profiles within TOAOCP. These skill profiles were:

- A – Moderate user;
- B – Advanced user;
- C – Slight computer knowledge;
- D – Social media user.

Students were told to select as many options from A to D as they required. The mean test scores against skill set were analysed, and Table 6.15 displays the results.

TABLE 6.15: Grouping of skill sets and test scores

Statistics	
	Actual Cognitive Test Percentage

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Moderate User	N	Valid	8
		Missing	0
	Mean		52.0833
	Std. Deviation		32.65683
	Variance		1066.468
	Range		100.00
ABCD	N	Valid	1
		Missing	0
	Mean		.0000
	Range		.00
AC	N	Valid	3
		Missing	0
	Mean		83.3333
	Std. Deviation		16.66667
	Variance		277.778
	Range		33.33
AD	N	Valid	11
		Missing	0
	Mean		53.0303
	Std. Deviation		33.18147
	Variance		1101.010
	Range		100.00
Advanced User	N	Valid	3
		Missing	0
	Mean		38.8889
	Std. Deviation		34.69443
	Variance		1203.704
	Range		66.67
BC	N	Valid	1
		Missing	0
	Mean		100.0000
	Range		.00
Slight User	N	Valid	7
		Missing	0
	Mean		71.4286
	Std. Deviation		15.85316

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	Variance		251.323
	Range		50.00
CD	N	Valid	5
		Missing	0
	Mean		70.0000
	Std. Deviation		24.72066
	Variance		611.111
	Range		66.67
Social, End User	N	Valid	15
		Missing	0
	Mean		38.8889
	Std. Deviation		18.54495
	Variance		343.915
	Range		50.00
E	N	Valid	5
		Missing	0
	Mean		60.0000
	Std. Deviation		34.56074
	Variance		1194.444
	Range		83.33

As discussed in the methodology (see Section 5.9.1.2) each participant rated their skill profile with computing. The slight users, or students who believed that their knowledge was on the lower end of the computer usage scale, scored an average of 71% (n=7) having the highest mean. The students rating their skill sets as "slight computer knowledge" on the instrumentation scored the highest in the test. Moderate and social computer users (n=11) scored 53% on the test. Advanced computer users had a mean test score of 38% (n=4) while slight and social combination users test scores were on average 70% (n=5). The students that classified themselves only as social users, where the computer is used only for social media purposes scored 36% on the test.

The skill set question and evaluation items were included to assess the learning comic. Once the evaluation data was collected, the structural equation model SEM analysis could be run. The first two SEMs were constructed specifically to answer particular research questions.

6.1.7 Structural equation models for impacts of pictures upon Cognition and Motivation

To answer research questions one and two, SEMs were constructed for pictures only so as to find the impact of each factor on the Self-Assessed Cognition and Motivation separately. The first model was specifically constructed to answer Research Question One that is: What are the impacts on cognition of using pictures in learning computer programming? The SEM constructed for cognition is shown in Figure 6.7.

FIGURE 6.7: SEM to assess impacts of pictures upon cognition

6.1.8 Assessing the measurement model

Reliability and validity of both the cognition and motivation models were passed. After these checks, a structural model assessment was performed with the criteria in Section 6. The criteria are summarised in Table 5.10, and the results are described in the next sections.

Reliability and validity
In Table 6.17 (three items, a = .475), the results show items loading above (p <.05). Convergent validity of the latent variables was therefore confirmed. Composite reliability coefficients were all above .7, which satisfies the minimum level. Average variance extracted (AVE) levels, which can be seen in Table 6.16 were all above .5 for the constructs except for Self-Assessed Cognition that was .475.

Reliability of Self-Assessed Cognition was .475, and that is under the acceptable threshold of .7. Despite this low measure, the other constructs within the model had high levels satisfying their reliability. According to Hair Jr et al. (2016), researchers should rely more on the AVE and composite reliability when dealing with partial least squares models in contrast to the Cronbach's alpha.

The cognition structural equation model (SEM) for pictures accounts for 95% of the total variance. There were two highly significant impacts upon Self-Assessed Cognition, that is, the perceived understanding of pictures when learning computer programming. The first impact was Self-Assessed Motivation which was found to be a significant predictor of Intent (β = .476, f^2 =.313, p < .001). The second significant predictor was Picture Representation (β = .361, f^2 =.131, p = .001). The highly significant impacts upon Self-Assessed Cognition (p = <.001) for the quantitative analysis of pictures were Self-Assessed Motivation as well as Factor 1 that measured Picture Representation.

Other impacts with p-values under .05 were Usefulness (β = .212, f^2 =.098, p < .042) and Flow (β = .224, f^2 =.127, p = .034). Understanding had a beta value of 0.196 and was just over the significance value with p = 0.056 (f^2 =.090). Table 6.17 provides a summary of the impacts upon Self-Assessed Cognition when using pictures to learn computer programming.
A structural equation model (SEM) was also carried out upon Self-Assessed Motivation. The second model was specially constructed to answer Research Question Two that is:

What are the impacts on motivation of using pictures to learn computer programming?

The motivation SEM can be seen in Figure 6.8 and accounts for 60% of the total variance. At first order factor level, there was one significant factor shown to impact on Self-Assessed Motivation. Picture Literacy was found to be a highly significant predictor of Self-Assessed Motivation (β = .387, f^2 =.242, p < .001). Understanding visual communication, more specifically Picture Literacy, impacts the Self-Assessed Motivation to use pictures in learning computer programming. Other factors that moderately impact Self-Assessed Motivation are Personal Ability (p=.045), Picture Representation (p=.013) and

TABLE 6.16: Cronbach's alpha, composite reliability and AVE

Construct	Cronbach's alpha	Composite	AVE	N
Ability	.836	.902	.755	59
Usefulness	.841	.905	.760	59
Simplicity	.885	.929	.813	59
Fear	.884	.929	.813	59
PictureLiteracy	.936	.936	.829	59
Clarity	.747	.857	.669	59
Confidence	.576	.780	.543	59
Motivation	.804	.886	.722	59
Prior Knowledge	.798	.883	.717	59
PictureRepresentation	.446	.730	.476	59
Flow	.754	.860	.675	59
Intent	.816	.891	.732	59
Fun	.797	.882	.715	59

AVE = Average variance extracted

TABLE 6.17: SEM influence of variables upon Self-Assessed Cognition (three items, a = .475)

Path	B	p-value	f2	Impact
Abilty ->SACog	.121	.168	.068	No
Usefulness ->SACog	.212	.042	.098	Yes
Simplicity ->SACog	.078	.271	.032	No
Fear ->SACog	.064	.309	.024	No
PictureLiteracy ->SACog	.041	.375	.024	No
Clarity ->SACog	.046	.361	.017	No
Confidence ->SACog	.196	.056	.090	No
SAMotivation ->SACog	.476	<.001	.313	Yes
Prior Knowledge ->SACog	.155	.107	.059	No
PictureRepresentation->SACog	.361	.001	.031	Yes
Flow ->SACog	.224	.034	.127	Yes
Intent ->SACog	-.004	.488	.002	No
Fun ->SACog	-.069	.294	.029	No

R^2 = .95; Adjusted R^2 = .94, Q^2 = .7, SACog = Self-Assessed Cognition

Self-Assessed Cognition (p=.049). Usefulness was just over the significance threshold (p=.059), despite having a beta value of close to .2 at .193.

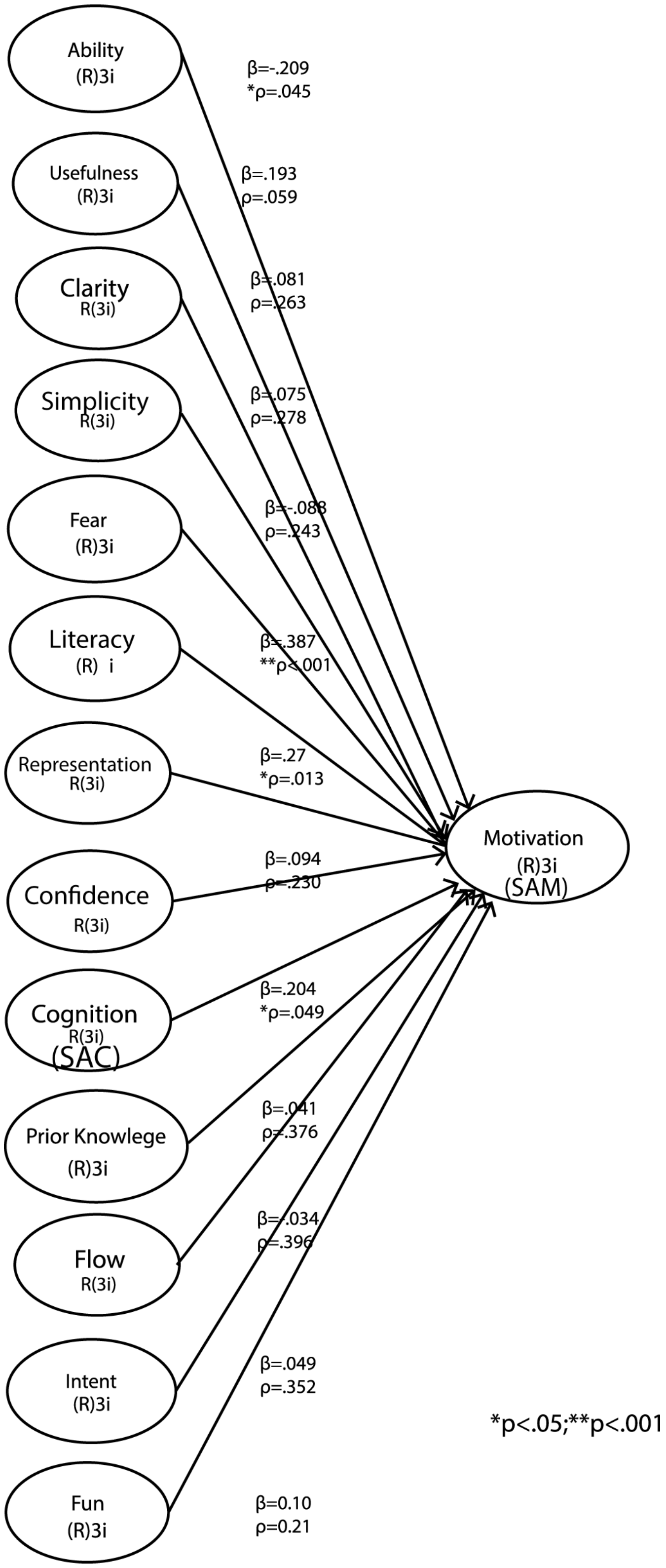

FIGURE 6.8: SEM to assess the impacts of pictures on motivation

Exploratory factor analysis

TABLE 6.18: SEM influence of variables upon Self-Assessed Motivation (three items, a = .722)

Path	B	p-value	f2	Impact
Abilty ->SAMot	.209	.045	.099	Yes
Usefulness ->SAMot	.193	.059	.055	No
Clarity ->SAMot	.081	.263	.030	No
Simplicity ->SAMot	.075	.278	.032	No
Fear ->SAMot	-.088	.243	.02	No
Literacy ->SAMot	.387	<.001	.132	Yes
Representation->SAMot	.27	<.05	.145	Yes
Confidence ->SAMot	.094	.230	.033	No
SACognition ->SAMot	.204	<.05	.242	Yes
Prior Knowledge ->SAMot	.041	.376	.016	No
Flow ->SAMot	.034	.396	.015	No
Intent ->SAMot	-.049	.352	.018	No
Fun ->SAMot	-.010	.21	.03	No

R^2 = .599; Adjusted R^2 = .493, Q^2 = .886, SAMot = Self-Assessed Motivation

The initial set of items was modified and assessed during the pilot test. The reliability and validity were adjusted within the instrumentation accordingly, until both reached a threshold level. As discussed, construct validity occurs through statistical testing and can only be performed with the data. Unlike content validity, construct validity cannot be performed with a literature review of the theory. I assessed construct validity by calculating the convergent validity within the software Statistical Package for the Social Sciences (SPSS). The convergent validity is the extent to which the items correlate with each other under one specific factor or construct. Construct is a term used instead of factor when discussing structural equation modelling. According to convergent validity, predicted items measuring a factor will load well into that factor. The convergent validity is calculated in SPSS through the average shared variance, or (AVE). The following formula calculates the AVE:

$$AVE = \frac{sumofsquarestandardisedfactorloading}{numberofitems} \tag{6.1}$$

Table 6.22 lists the AVE values for each picture construct. The percentage of variance is the value of the AVE and should be above a threshold of .5 to support that construct's convergent validity. All constructs are greater than .5, that is the acceptable level of AVE as listed before and acknowledged in Table 5.10. An AVE of less than .5 may affect the validity of that construct, meaning that the items do not adequately address that particular factor.

Significant findings within the quantitative analysis exploratory factor analysis

The literature review revealed several variables that would impact on the motivation and cognition of visual communication. An existing study was examined, and modified, to reflect the constructs that may fit a visual communication model for a learning comic (Doty & Glick, 1998; Iten & Petko, 2014; Podsakoff et al., 2012). The constructs were adapted from the theory of planned behaviour and existing technology access models. They form the basis of the attitudes towards learning through pictures and comics. Five constructs were utilised from the TAM2 proposed by Venkatesh et al. (2003). The first three constructs came from Davis' original 1989 TAM and are Usefulness, Simplicity and Intent to use. The Personal Ability factor came from Venkatesh (2003). The constructs of Fun and Enjoyment; and Fear were considered as measures that would also impact on a person's attitudes towards a learning comic. The final three constructs were introduced to the study to evaluate the learning comic. These three are: Self-Assessed Motivation (or Motivation), Self-Assessed Cognition (SAC) and Flow. The factors within the EFA as well as the adaption of the existing TAM instrumentation are now discussed starting with Usefulness. All adaptions of the TAM are listed in Appendix B.

Usefulness or perceived usefulness (PU) refers to what is expected from a piece of technology, or in the case of TOAOCP what an individual expects from a digital artefact. The expectation here is that the participant understands the content from the artefact and finds it useful.

Simplicity, which is also known as perceived ease of use (PEOU) , was the second variable measured. PEOU combines judgements about self-efficacy (Davis, 1989) and outcome judgements (Bandura, 1982, p. 22). A self-efficacy judgement is a measure of how a person can execute an action that is required to deal with a prospective situation. In contrast, outcome judgements are made by someone concerning a future act, that is to say one based upon a previous successful act. The first two variables PU and PEOU form the basis of the TAM.

Fun and Enjoyment was the next variable measured as part of the TAM and was based on a study by Moon and Young-Gul (2000). Moon's study adapted a TAM by adding a playfulness construct. Other researchers, Thomas Chesney and John Sherry both incorporated Fun and Enjoyment into the TAM model (Chesney, 2006; Sherry, 2004). Although I am aware that computer programming is at times a context that is largely devoid of Fun and Enjoyment, it was necessary to add this variable to the TAM for the following two reasons. Firstly, comics and pictures are more commonly enjoyed within a recreational context by adolescents. A learning comic of the type proposed within this research, is far less common and this may alter the fun/enjoyment aspect of the study. A learning context may alter the relationship between fun/enjoyment of pictures or comics upon the intent to learn. The second reason that a Fun and Enjoyment construct was included was to examine its relationship to flow theory.

Flow theory, which is also known as deep enjoyment, was included within the evaluation section of the instrumentation. Fun and Enjoyment is connected to flow theory and has been associated with learning generally as well as with learning games

(Csikszentmihalyi, 1997, 2008b, 1996; Admiraal et al., 2011; Sherry, 2004). The Fun and Enjoyment construct has been included within the model to measure the relationship that it has to flow. Additionally, I also wanted to measure this construct affect upon gamification elements. Gamification is discussed further along in its own section as it is also related to flow theory. Both gamification and flow list the Fun and Enjoyment variable as one of their impacts.

The fifth variable is Fear and is a negative affect. This can lead to stress and anxiety among learners. In the context of this research fear of learning computer programming was addressed as well as a fear of learning through visual communication.

The previous five factors that assess Attitudes will now be analysed with an exploratory factor analysis (EFA). In order to understand if these five factors could be used as they were researched in the literature review, a factor analysis was performed. The EFA occurred during Research Phase Two of the study. The history of the development of the TAM factors has been discussed and an explanation of how the additional evaluation factors are adapted for TOAOCP now continues.

Adaptions of the factors that make up the evaluation section of the model are now examined. Some factors that were adapted that assess Attitudes were from a TAM model by Iten et al., (2014). The scale was also modified for these from Iten and Petko (2014). Other variables that are measured by Perceived behavioural control (PBC) were also examined as the research design was exploratory.

Perceived behavioural control (PCB) was a measure taken to gauge how comfortable the participants were with the use of a comic. The measure was only adapted for the design element of comics from the Iten et al., (2014) study (items 3.37, 3.38, 3.39). Participants were assessed on how in control of learning programming they felt when they were using the learning comic.

Self-Assessed Cognition (SAC) was adapted from the Iten et al., (2014) study and was adapted from a variable called cognitive learning gain to Self-Assessed Cognition (SAC). The scale assessed whether or not the participant had an increased self-assessed knowledge of computer programming when learning through visual communication. This variable was singular in that the three items of 3.19, 3.20 and 3.21 were used for both design elements.

Self-Assessed Motivation (SAM) was also adapted from the same study as Self-Assessed Cognition. The scale assessed if the pictures and comic had motivated the participant to learn computer programming. A single measure was used to assess both design elements. The items 3.22, 3.23 and 3.24 made up the measure for Self-Assessed Motivation (or Motivation for short).

This section concludes how the items were adapted from another study. The results from the exploratory factor analysis (EFA) will now be examined. The analysis inspects whether the adapted factors could be used in the way that the research related in the literature review.

Results from the exploratory factor analysis for pictures

Factor analysis allows a researcher to measure a construct that is based on the data gathered from the observed variables. More formally, Field (2013) defines factor analysis as:

> A multivariate technique for identifying whether the correlations between a set of observed variables stem from their relationship to one or more latent variables in the data, each of which takes the form of a linear model. (Field, 2013, p. 786)

A sample size must be suitable for factor analysis before calculation. The number of participants that gave data for the quantitative analysis was 59 (n = 59). There are mixed opinions about the minimum number of participants that a researcher can have in a study that requires factor analysis. Some statisticians believe a large sample size, such as 300 is required (Guadagnoli & Velicer, 1988) while others state that it is the research design that determines the data's suitability for analysis (MacCallum et al., 1999). Guadagnoli and Velicer (1988) also stated that, "An N of 50 was the minimum needed to reproduce the pattern" (p. 265). While Field suggested that "With all communalities above 0.6, relatively small samples (less than 100) may be perfectly adequate" (2013, p. 647).

Kaiser Meyer-Olkin (KMO) and Bartlette's test of sphericity was another measure used to determine the data's suitability for factor analysis. KMO values between 0.5 and 0.7 are mediocre, values between 0.7 and 0.8 are good and according to Field (2009), values of about 0.8 are superb. As the value of KMO in TOAOCP was .737, for pictures, the data had 'good' suitability. The significance of this test was less than .001 therefore the data gathered on pictures was "suitable for factor analysis" (Matroni, 2015b, p. 51).

A scree plot is used within factor analysis to its associated eigenvalue. Eigenvalues represent the strength of the relationship in a linear equation between two variables. The scree plot shows each factor's importance and has a very characteristic shape (Field, 2013b; Stevens, 2002). Figure 6.9 shows the scree plot for the picture factors.

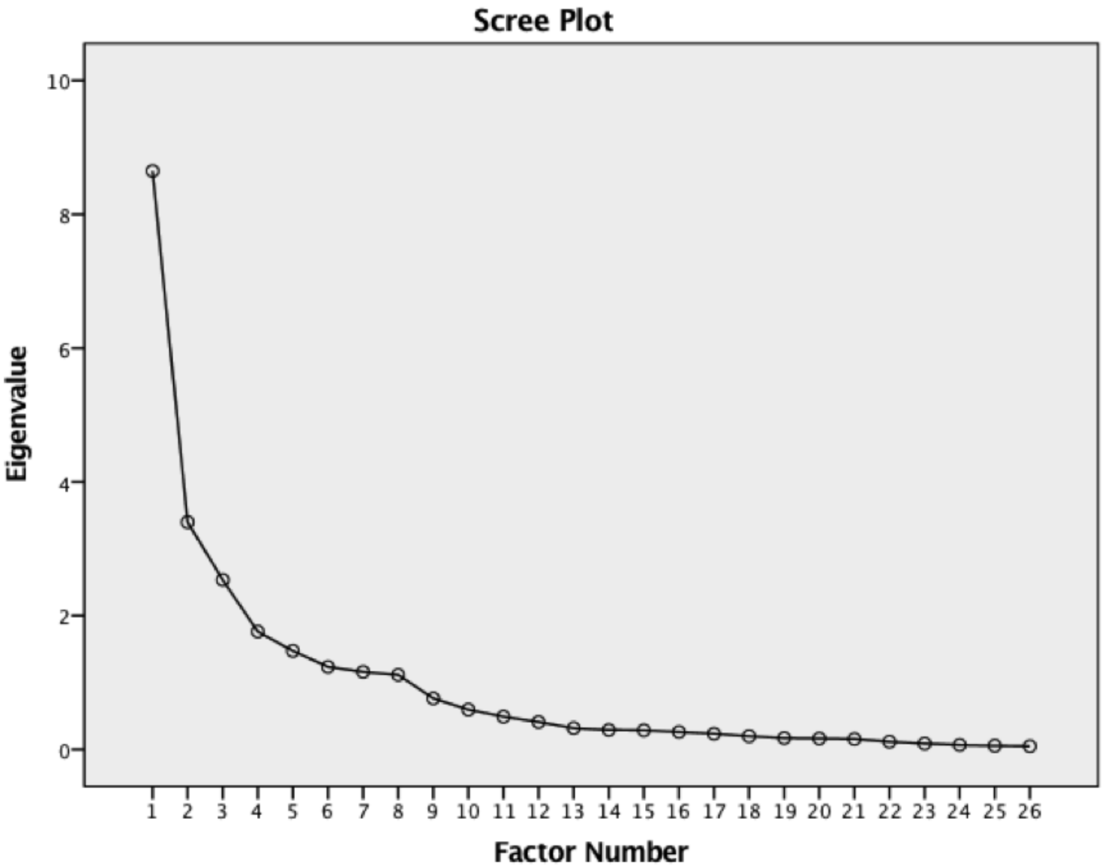

FIGURE 6.9: Scree plot for picture factor analysis

An inflection is a point on a curve where the direction of the curvature changes. There are two points of inflection on the screen plot for picture factors. There is a point at Factor 6, where the curvature changes, and a point at Factor 9. Since the second point of inflection is at point nine, an eight factor solution is appropriate for the picture analysis. Scree plots are used alongside of a factor pattern matrix to analyse factors within exploratory factor analysis.

A pattern matrix is a type of output from an SPSS calculation of factor analysis. This matrix contains information on the unique contribution of a variable to a factor and depicts independence or dependence between factors. Factors from one to eight had quite high loadings and were acceptable to check for validity and reliability. Only two items, 3.20 and 3.24 were not above .5, which is the minimum recommended by Hair et al. (2010).

TABLE 6.19: Pattern matrix for picture factor loadings

Pattern Matrix Factor	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**
Representation3.14	.851							
Representation3.15	.841							
Literacy3.17	.689							
Literacy3.16	.628							
Literacy3.18	.529							
Fear1.14		.929						
Fear1.15		.818						
Fear1.13		.800						
Usefulness1.3			.743					
Usefulness1.1			.738					
Usefulness1.2			.646					
PriorKnowledge3.5				-.846				
PriorKnowledge3.6				-.844				
Flow3.8				-.540				
PersonalAbility1.12					-.894			
PersonalAbility1.11					-.729			
Flow3.9					-.538			
SAM3.23						.854		
SAM3.22						.720	.312	

continued ...

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Pattern Matrix Factor	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**
SAC3.21						.691		
FunEnjoyment1.7							.864	
FunEnjoyment1.8							.827	
Simplicity1.6							.556	
Intention1.17								.685
Intention1.18								.681
Intention1.16								.605

Extraction Method: Principal Axis Factoring.

Rotation Method: Oblimin with Kaiser Normalization.a

a. Rotation converged in 12 iterations.

The Table 6.19 shows the factor items after rotation. The items that cluster or load into the same factors suggest that Factor 1 represents the Literacy and Representation of pictures, Factor 2 a Fear of learning through a picture, Factor 3 Usefulness in learning with pictures, Factor 4 represents Prior Knowledge of computer programming, Factor 5 is predominantly Self-Assessed Motivation and pictures, Factor 6 is Personal Ability when learning with pictures, Factor 7 is intent to use pictures and Factor 8 is Fun and Enjoyment of pictures. These eight factors account for 82% of the variance as shown in Table 6.20. Pictures that had a loading of less than .50 were dropped from further analyses on pictures, and thus the factor analysis was repeated without these items.

In summary, a principal axis factoring analysis was conducted on the 15 items with Oblimin and Kaiser normalization rotation. The KMO measure verified the sampling adequacy for the analysis, KMO = .741 ('good' according to Field, 2009). The scree plot had a point of inflection after six and so the analysis is suitable to five factors. Furthurmore, Bartlette's test of sphericity was not significant, thus indicating that the data was suitable for factor analysis.

TABLE 6.20: Total variance explained table for the picture exploratory factor analysis

Factor	**Total**	**% of Variance**	**Cumulative %**	**Total**	**% of Variance**	**Cumulative %**	**Total**
1	8.648	33.262	33.262	8.405	32.328	32.328	5.477
2	3.397	13.066	46.328	3.178	12.222	44.550	2.932
3	2.534	9.747	56.075	2.281	8.771	53.322	3.587
4	1.760	6.770	62.845	1.522	5.855	59.177	3.707
5	1.472	5.660	68.505	1.238	4.763	63.940	3.959
6	1.233	4.741	73.246	.965	3.711	67.651	3.295
7	1.158	4.454	77.700	.860	3.310	70.960	3.742
8	1.113	4.282	81.982	.810	3.116	74.076	3.638

TABLE 6.21: The structure matrix for the picture model

Structure Matrix Factor	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**
Representation3.15	.872				-.391	.401		
Literacy3.17	.850			-.479	-.404	.475		.317
Representation3.14	.831			-.345				.411
Literacy3.16	.819		.389	-.455	-.364	.365	.540	
Literacy3.18	.737		.308	-.491	-.525	.406		.332
Fear1.14		.952						
Fear1.15		.831						
Fear1.13		.799			-.358			
Usefulness1.3	.309		.859		-.313		.476	.420
Usefulness1.2		.791	-.444	.320				.467
Usefulness1.1		.732						
PriorKnowledge3.5	.438			-.880				.326
PriorKnowledge3.6				-.851				
Flow3.8	.495	.306		-.702	-.410			
PersonalAbility1.12	.397		.376		-.937			
PersonalAbility1.11	.341		.351		-.809	.318	.306	.373
Flow3.9				-.325	-.580			
SAMotivation3.23		.403					.899	
SAMotivation3.22	.463					.795	.426	

continued . . .

. . . continued

Structure Matrix Factor	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**
SACognition3.21					-.314	.702		
FunEnjoyment1.7			.333				.894	.317
FunEnjoyment1.8	.328						.870	
Simplicity1.6	.318	-.303	.496				.746	.337
Intention1.18	.441		.360		-.409		.328	.796
Intention1.17	.325		.421		-.399		.790	
Intention1.16			.311	-.313			.686	

These factors included the dimensions used to measure the technology acceptance model (TAM) that are Usefulness (three items), Fear (three items), Prior Knowledge (three items) and Personal Ability (three items). The other factors are Fun (three items), Intention (three items), Self-Assessed Cognition (five items) and Self-Assessed Motivation (three items). This structure was revised in the measurement model assessment section, where reliability, convergent and discriminant validities were analysed until all items reached the minimum thresholds required.

Adaption of the picture factors

A brief section has been included on how the factors were adapted from the TAM. As well as these adapted factors, new measures were created for TOAOCP to measure the persuasive ability of pictures. All factors are discussed concerning the items listed in Table 5.4. All responses were obtained on a five-point Likert scale (1- strongly disagree; 5 – strongly agree). The original scale from Iten et al., (2014) is listed in Appendix B along with the adaptions made for TOAOCP.

The items for visual Literacy and Representation (3.16, 3.18 and 3.13, 3.14, 3.15) loaded into Factor 1 within the EFA for pictures. I made these scales up to measure the effectiveness of the pictures within the instrumentation. The validity of Factor 1 was .918 and this was the first factor that loaded in the EFA. The four items loaded into the measure above .5. The recognisability of the pictures was an important feature to the students. The four-item scale of 3.14, 3.15, 3.16, and 3.18 was used to measure this factor. These items were made up to suit TOAOCP and proved to be an important measure as well as the dominant exploratory factor to load. Both the items are listed in Table 6.22 under engagement and representation. The items that make up Factor 1 are as follows:

3.14: I felt confident I learnt something new with the pictures.

3.15: When looking at the pictures, I understood the concepts.

3.16: The pictures explained things.

3:18: The pictures revealed information to me.

Factor 2 measured Fear of using or pictures to learn to program (see Table 6.22). Fear has a negative affect upon an individual's learning. The presence of fear has been linked to stress and anxiety among learners. In the context of this research, fear of learning computer programming was addressed as well as a fear of learning through visual communication. This measure was adapted from Iten et al., (2014). Fear as a result of integrating pictures and comics into learning computer programming was assessed. Participants were asked about understanding, misinterpretation and making a mistake as part of the adaption for pictures (items: 1.13, 1.14, 1.15). Within the adaption for comics, participants were asked about fear of using a paper prototype and also their understanding of learning through a comic (items 2.13, 2.14, 2.15). All three items loaded into Factor 2 to measure fear of learning to program through pictures and had a validity of .839.

TABLE 6.22: Summary of the exploratory factor analysis for pictures

Total variance explained

	Factor loading	Cronbach's alpha	AVE
Factor 1 (n = 5)			
Representation3.14	.851	.918	.939
Representation3.15	.841		
Literacy3.17	.689		
Literacy3.16	.689		
Literacy3.18	.529		
Factor 2 (n = 3)			
Fear1.14	.929	.882	0.929
Fear1.13	.818		
Fear1.15	.800		
Factor 3 (n = 3)			
Usefulness1.1	.743	.839	.905
Usefulness1.2	.738		
Usefulness1.3	.646		
Factor 4 (n = 3)			
PriorKnowledge3.5	-.846	.850	.910
PriorKnowledge3.6	-.844		
Flow3.8	-.540		
PersonalAbility1.12	-.894	.824	.814
PersonalAbility1.11	-.729		
Flow3.9	-.538		
Factor 6 (n = 3)			
SAMotivation3.23	.854	.824	.742
SAMotivation3.22	.720		
SACognition3.21	.691		
FunEnjoyment1.7	.864	.881	.809
FunEnjoyment1.8	.827		
Simplicity1.6	.556		
Factor 8 (n = 3)			
Intention1.17	.685	.816	.732
Intention1.16	.681		
Intention1.18	.605		

Usefulness or Perceived Usefulness (PU) refers to what is expected of a piece of technology, or in the case of TOAOCP what an individual expects from a digital artefact. Usefulness as a result of integrating pictures into learning was assessed and was measured using an adaption of the scale developed by Iten et al., (2014) through items 1.1, 1.2, 1.3 and 2.1, 2.2, 2.3. Based on factor analysis and reliability analysis, no items were dropped. The final three-item scale, Factor 3, had a reliability of .839 (see Table 6.22).

Factor 4 loaded two items measuring Prior Knowledge (3.5, 3.6) and one measurement item for Flow (3.8). These items were adapted from the same study as Iten et al., (2014). In items 3.5 and 3.6 the participants were asked if it was important that they know about programming. In item 3.8 the wording was adapted from “While playing” (Iten, 2014) to "In the lesson" within the instrumentation (see Appendix A). Factor 4 had a validity of .85.

The next construct of Fun and Enjoyment has been defined and discussed previously in Section 4.5.3. Two of the Fun and Enjoyment items loaded into Factor 7. Fun has been adopted for TOAOCP to find any relationship it has upon learning through pictures and learning through comics. This measure was an adaption of the scale developed in Iten et al., (2014) and was measured by items 1.7, 1.8, 1.9 for pictures and 2.7, 2.8, 2.9 for comics.

Personal Ability was a measure of how well an individual believes they can learn to program on their own, firstly through using pictures (items 1.10, 1.11, 1.12) and then through a comic (items 2.7, 2.8, 2.9). This measure was adapted from Iten et al., (2014). A person’s self-belief in their ability to program was assessed, and how this impacted upon how they would be able to learn if no help was available. The items 1.11 and 1.12 were kept in the study and an item that measures Flow, 3.9, ended up loading into Factor 5 as well. Item 1.10 was dropped from the final model (because of a low loading value) and the validity was .824.

Fun was quite impactful upon learning to program through pictures, but it was less impactful when learning to program from a comic. The aspect of Fun and Enjoyment not loading highly with the comic design elements is discussed in more detail in Section 6.1.3. Table 5.4 lists the items that were modified from the Iten et al., (2014) study as 1.7, 1.8 and 1.9 for pictures and 2.7, 2.8 and 2.9 for comics. The factor of Fun was modified generically and examined the impacts of pictures on learning only. Fun and Enjoyment loaded into Factor 7 with a reliability of .881 and is listed in Table 6.22.

Adaption of the factor of Intent occurred through the modification of an existing scale in Iten et al., (2014). Participants were assessed upon their learning through comics and pictures separately, unless otherwise stated. The factor of Intent was assessed from two separate factors where the same first two items were asked within each (items 1.16, 1.17 and items 2.16, 2.17). The last item was adapted for each design element (items 1.18 and item 2.18), and all three items loaded into Factor 8 for the EFA of pictures and the validity was .816 (see Table 7-20).

Simplicity was also included within the variables that measure perceived ease of use (PEOU) as defined and discussed in Section 4.5.3. How simple the learner perceives the pictures are to use was assessed as a measure, and this is listed in Table 6.6 as 1.4, 1.5 and 1.6 for pictures and as 2.4, 2.5, and 2.6 for comics. This scale was an adaption of the scale used in Iten et al., (2014). Items 1.4 and 1.5 failed to reach minimum loading for the picture model and were therefore dropped from the analysis. Two items for Simplicity did not load highly, and later it is also discussed that Fun and Enjoyment did not load highly for the comic exploratory factor analysis (EFA). Item 1.6 loaded into Factor 7 along with two items that measure Fun and Enjoyment and are discussed in the next section.

Results from the exploratory factor analysis for comics
An extra set of items was included in the EFA for comics to measure the Subjective Norm. The Subjective Norm within TOAOCP assesses what the people within someone's social environment feel about that individual using a comic to learn with. Three types of people within the student's environment were taken into account. These included friends, family and parents, which are documented in the following three items:

3.40: My friends would like if I learnt through this type of comic.

3.41: My parents would like if I learnt though this type of comic.

3.42: My family would like if I learnt through this type of comic.

As a participant could have no siblings however still be part of a family, item 3.42 was included in the quantitative measures. Item 3.41 could be the same measure as item 3.42 if the child were an only child which can be considered a small limitation of TOAOCP. These items were included to measure if comics were a useful and an effective style of learning medium, despite the standard style of textbooks within the schools not being structured like a comic. The reasons for more in depth research about the Subjective Norm (SN) and comics have been addressed in Section 4.5.

The scree plot for comics revealed an inflection at point seven indicating that a five-factor result of the comic EFA was appropriate. The scree plot for the EFA and comics can be seen in Figure 6.10. The factors are Personal Ability (Factor 1) Intent to use (Factor 2), Subjective Norm (Factor 3), Fear (Factor 5) and Strategy (Factor 6). One item cross-loaded into both Factors 2 and 5. The item was left in the analysis as the scree plot (see Figure 6.10) indicated a five-factor analysis. The intention factor (Factor 4) only loaded two items into the factor. The last intention item failed to load into any of the factors highly enough to qualify in the factor analysis. This could have been improved by contextualising the question further. The two-item measure for intent to use comics did not reach an average variance extracted (AVE) of above .5. As this threshold was not reached the reliability is not as strong as a construct with a three-item measure. As the other items had quite high factor loadings, I have still used the two-item measure for Factor 4. The reliability of Factor 4 could be improved for TOAOCP. Hair (2010) explains that reliability can be lower when using exploratory analysis, however, he refers to the Cronbach's alpha value (or the latent variable). As the alpha value was between .6 and

.7 instead of reaching the threshold of .7, which is considered as valid for exploratory research. He states:

> Once a scale is deemed unidimensional, its reliability score, as measured by Cronbach's alpha:
>
> > * Should exceed a threshold of .70, although a .60 level can be used in exploratory research. (Hair et al., 2014, p. 125)

TOAOCP uses new measures and is a preliminary study and classified as exploratory research. As the AVE value was within a few points of acceptable (0.5) and is reliable, then validity is established for a preliminary or exploratory study.

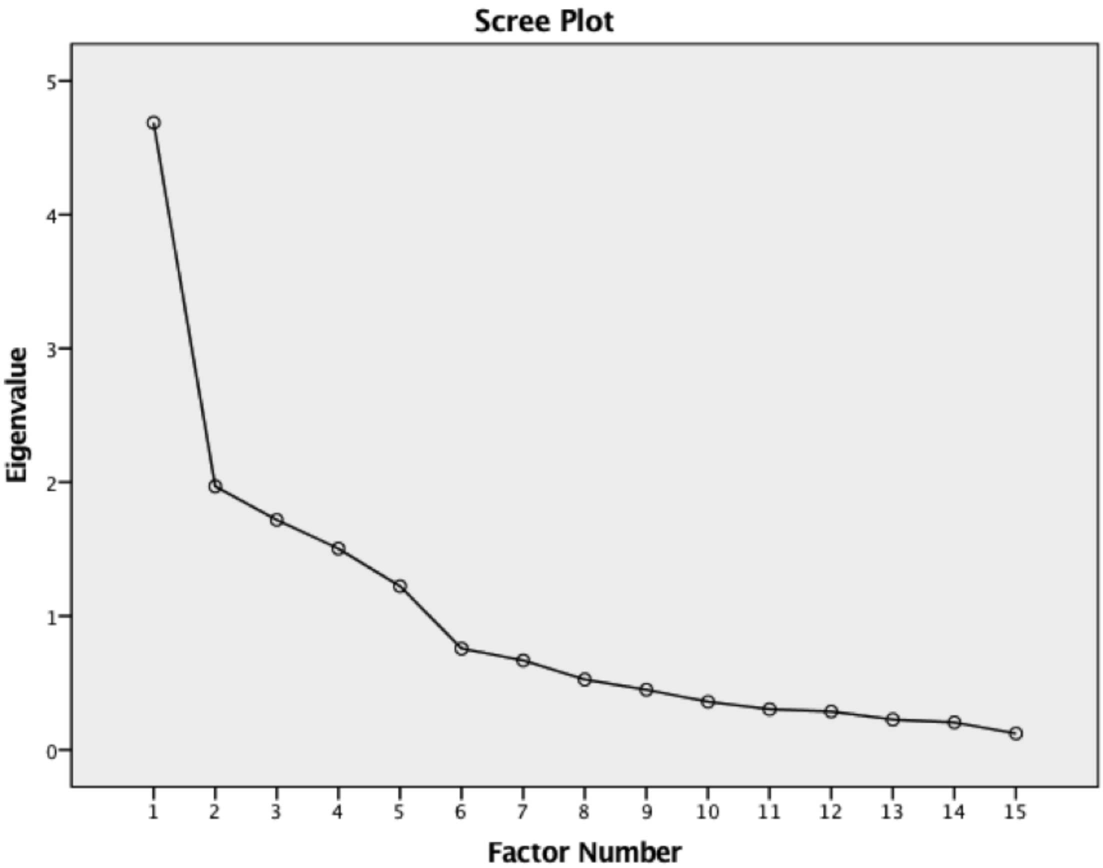


FIGURE 6.10: Scree plot for comic factor analysis

KMO and Bartlett's test were both .676, and not significant. The first five factors counted for 74 % of the variance as listed in Table 6.25. The factor that loaded first into the pattern matrix was the Subjective Norm. Three items loaded into this factor as well as an item measuring Self-Assessed Motivation. These factors all loaded above the .05 level which is the benchmark for Hair's analysis (Guadagnoli & Velicer, 1988).

TABLE 6.23: Pattern matrix for comic EFA

Pattern Matrix

	Factor				
	1	2	3	4	5
PersonalAbilityPostTest2.11Comics	.863				
FlowPostTest3.9	.760				
PersonalAbilityPostTest2.10Comics	.651				
IntentionToUsePostTest2.17Comics		.822			
FlowPostTest3.7		.563			.352
IntentionToUsePostTest2.18Comics		.555			
ComicSubjectiveNorm3.41			.878		
ComicSubjectiveNorm3.42			.748		
ComicSubjectiveNorm3.40			.671		
FearOfUsePostTest2.14Comics				.793	
FearOfUsePostTest2.13Comics				.728	
FearOfUsePostTest2.15				.585	
ComicStrategy3.26					.880
ComicUnderstanding3.29					.546
ComicStrategy3.27					.517

Extraction Method: Principal Axis Factoring.
Rotation Method: Oblimin with Kaiser Normalization.a
a. Rotation converged in 14 iterations.

The structure matrix indicates the cross loadings of the other factors and can be seen in Table 6.24. This matrix indicates all the loadings for the final factors.

TABLE 6.24: Structure matrix for the comic EFA

Structure Matrix

	Factor					
	1	2	3	4	5	6
ComicSubjectiveNorm3.41	.854		-.336			.398
ComicSubjectNorm3.40	.769	.395	-.320		-.303	
MotivationalLearningEffectComic3.36	.761		-.458	.397		.526
ComicSubjectieNorm3.42	.658					.437
FearOfUsePostTest2.14Comics		.901				
FearOfUsePostTest2.13Comics		.755	-.381			
FearOfUsePostTest2.15		.607		.395		
PersonalAbilityPostTest2.12Comics		.319	-.831		-.364	.424
PersonalAbilityPostTest2.11Comics		-.812				
PersonalAbilityPostTest2.10Comics			-.805		-.426	
IntentionToUsePostTest2.16Comics	.465		-.375	.826		
IntentionToUsePostTest2.17Comics				.662	-.312	
UsefulnessPostTest2.1Comics	.408		-.425		-.905	
UsefulnessPostTest2.2Comics	.432		-.543	.370	-.817	.337
CognitiveLearningEffectComic3.32	.556		-.461			.819
CognitiveLearningEffectComic3.33	.423		-.461			.802
ComicUnderstanding3.28	.471		-.415		-.357	.721
ComicStrategy3.25					.716	

TABLE 6.25: Total variance explained for the comic EFA

Factor	Total	% of Variance	Cumulative %	Total	% of Variance	Cumulative %	Total
1	4.688	31.253	31.253	4.326	28.837	28.837	2.891
2	1.969	13.129	44.382	1.617	10.783	39.620	1.820
3	1.718	11.455	55.837	1.369	9.125	48.745	2.581
4	1.504	10.025	65.862	1.080	7.197	55.942	2.279
5	1.223	8.155	74.018	.886	5.905	61.846	2.383

To understand what relationships exist between each of the comic factors, a linear regression analysis was performed on each. Each factor was tried as the independent variable to see if other factors correlated with it. Linear regressions were also calculated after the factor analysis to determine the significant correlation paths that exist in the creation of the picture structural equation model (SEM). As SEM is considered more powerful than linear regression analysis, only some regressions are included. Before SEM is discussed, a description of the adaption of the comic scale will be covered.

Adaption of the comic factors

How the factors were adapted from the TAM for comics is now addressed. All factors are discussed concerning items listed in Table 5.4. The responses were obtained on a five-point Likert scale (1- strongly disagree; 5 – strongly agree). The original scales along with the adaptions are listed in Appendix B.

The items for visual Personal Ability and Flow (2.11, 2.10 and 3.9) loaded into Factor 1 within the EFA for comics. The validity was .671 which failed to meet the required threshold of .7. This could mean that the scale is weighted incorrectly for the items and the measure for Factor 1 could be improved by including more items in the measure such as 3.42 (Subjective Norm) that also loaded into Factor 1. Three items were used in the measure. Factor 2 also had three items in the measure (2.17, 3.7 and 2.18). This factor was unreliable, as the Cronbach's alpha, with a value of .463, did not reach the minimum threshold of .7.

Three items were used to measure Factor 3 (3.41, 3.42 and 3.40). The reliability was .808 meaning that the minimum threshold had been reached. This factor assessed how important the opinions of family and friends were when learning programming from a comic. These items were adapted from an original scale in Iten et al., (2014) (see Appendix B). Factor 4 measured fear of using a comic. The adaption of the scale can be seen in Appendix B. Fear of using a comic was assessed with this measure (2.13, 2.14 and 2.15). The reliability was good, namely or .766, and three items were used. Factor 5 was a new measure created for TOAOCP concerning items about strategy and understanding. These items were not adapted and were created to assess the effectiveness of visual communication, engagement and goals. The items that loaded into factor 5 were:

TABLE 6.26: Summary of the exploratory factor analysis for comics

Total variance explained	**Factor loading**	**Cronbach's alpha**	**AVE**
Factor 1 (n = 3)			
PersonalAbilityPostTest2.11Comics	.863	.671	.728
FlowPostTest3.9	.760		
PersonalAbilityPostTest2.10Comics	.651		
Factor 2 (n = 3)			
IntentionToUsePostTest2.17Comics	.822	.463	.653
FlowPostTest3.7	.563		
IntentionToUsePostTest2.18Comics	.555		
Factor 3 (n = 3)			
ComicSubjectiveNorm3.41	.878	.808	.734
ComicSubjectiveNorm3.42	.748		
ComicSubjectiveNorm3.40	.671		
Factor 4 (n = 3)			
FearOfUsePostTest2.14Comics	.793	.766	.684
FearOfUsePostTest2.13Comics	.728		
FearOfUsePostTest2.15	.585		
Factor 5 (n = 3)			
ComicStrategy3.26	.880	.716	.641
ComicUnderstanding3.29	.546		
ComicStrategy3.27	.517		

3.26: During the lesson I did not care about what the comic was communicating I just wanted to finish.

3.29: When I learn visually, I'm learning the wrong way.

3.27: I was only interested in learning from the comic if it explained things the best way to me.

The reliability of the factor was good .716 and the loadings were above .5.

The structural equation models for the analysis are now discussed.

6.1.9 Structural equation models

Two separate models were produced from the structural equation modelling software WarpPLS (partial least squares) to support the hypotheses. The separate models were intended to represent two different design elements. Two perspectives of design and learning were measured. The first model produced was from the picture data while the second model concerned comics. The picture model will now be discussed with reference to Section 5.2.

Structural equation model for picture data
After analysis of the linear regressions, a final model was constructed for SEM analysis. The SEM analysis for pictures tested seven hypotheses.

H1p: Participants who intend to learn computer programming more, also report the pictures as being more useful.

H2p: Participants who find the pictures to be more useful, also report having more fun and enjoyment when learning computer programming.

H3p: Participants that have more fun when learning computer programming through pictures, have less fear of it.

H4p: Participants that find they have more prior knowledge about computer programming, believe the pictures to be more useful.

H5p: Participants with more understanding of the pictures about programming, also rely more on their prior knowledge.

H6p: Participants with more motivation when learning programming through the pictures, also report understanding programming more.

H7p: Participants with more ability to learn programming through pictures, also report they understand the pictures more.

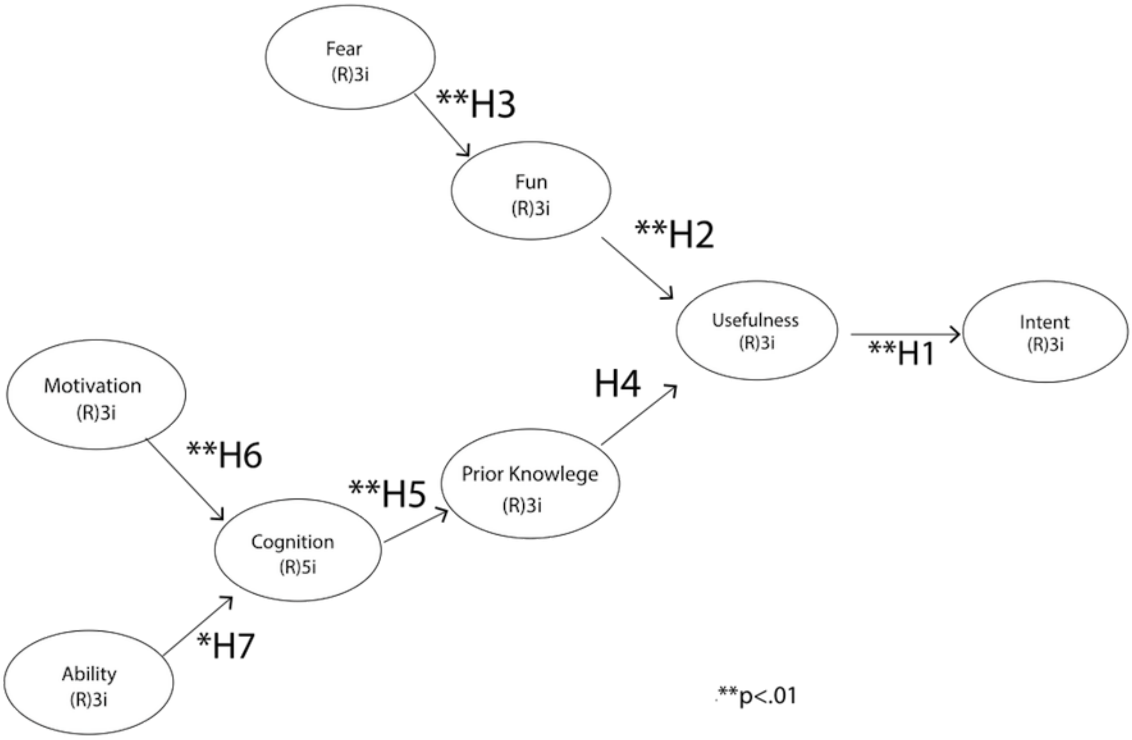


FIGURE 6.11: PLS-SEM results for pictures

In Table 6.27, Usefulness is the strongest predictor of Intent, with a path coefficient of .54 (p<.001), which is strong.

Multicollinearity of the model was checked through the average variance inflation factor (AVIF) and average full collinearity variance inflation factor (AFVIF) as sometimes multicollinearity can substantially reduce an estimator's efficiency (Bollen, 2011). The cut off points used for these values were 3.3 as ideal and 5 as acceptable. AVIF for the comic model was 1.089 and AFVIF for the comic model was 1.652, both of which were well under the recommended 3.3 and 5 respectively.

Structural equation model for comic data
The structural equation model for comics was constructed with the formulation of hypotheses in Section 4.6. The seven hypotheses tested are:

H1c: Participants with more intent to learn programming through a comic, also report higher belief in their personal ability to program.

H2c: Participants with more personal ability, also report placing more importance on what friends and family think of them learning through a comic.

TABLE 6.27: Structural model parameters for pictures

Path	B	p-value	f^2	Hypotheses
Attitudes towards learning with pictures				
Usefulness->Intent	.54	<.001	0.294	H1p: supported
Fun->Usefulness	.48	<.001	0.252	H2p: supported
Fear->Fun	-.41	<.001	0.171	H3p: supported
Evaluation of using pictures to learn programming				
PriorKnowledge->Usefulness	.18	.07	0.053	H4p: not supported
Cognition->PriorKnowledge	.58	<.001	0.338	H5p: supported
Motivation->Cognition	.48	<.001	0.282	H6p: supported
Ability->Cognition	.86	.002	0.181	H7p: supported
R^2 = .314, Adjusted R^2 = 0.298				

H3c: Participants with more understanding of pictures when read in sequence, also report having higher belief in their personal programming ability.

H4c: Participants with more strategy, report having lower fear of learning programming through a comic.

H5c: Male and female individuals differ in their intent to learn programming through a comic.

H6c: Participants that care more about what their friends and family think about learning computer programming from a comic, also report higher belief in their ability to learn from a comic.

H7c: Participants that are older, report caring less about what their friends and family think about learning computer programming through a comic.

The model in Figure 6.12 was the result for the comic SEM analysis containing seven significant paths. These paths represent the hypotheses. The parameters for the structural model are listed in Table 6.28.

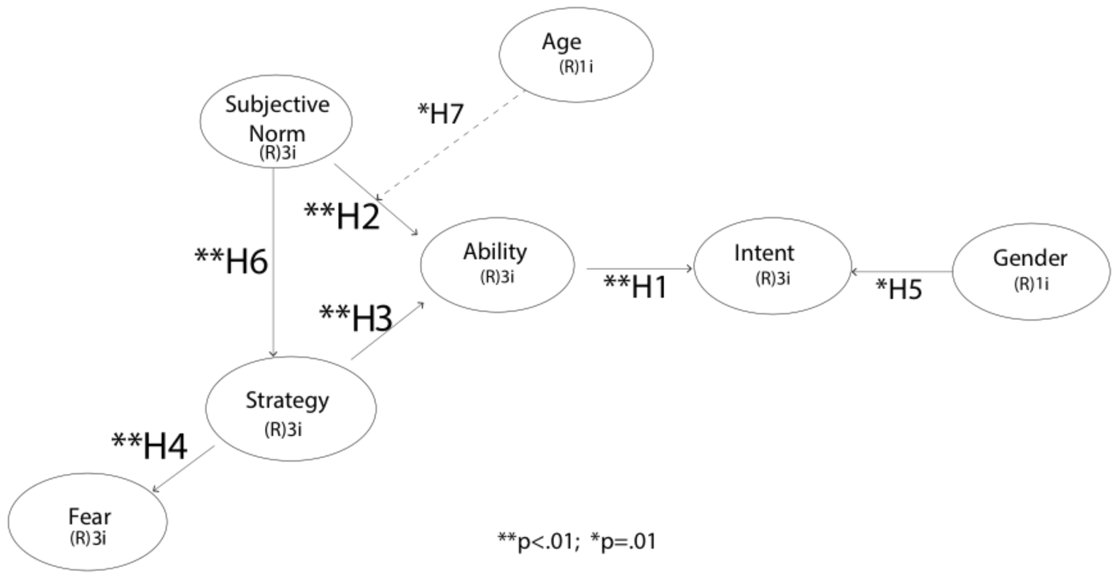


FIGURE 6.12: PLS-SEM results for comics

In Table 6.28 Ability is the strongest predictor of Intent, with a path coefficient of .468 (p <.001), which is considered strong (Guadagnoli & Velicer, 1988, p. 265). From a practical point of view, the effect size of the Ability-Intent path further shows the effect of Ability was (f^2 = .233). The path coefficient of Subjective Norm was ideal, with a medium effect size (= .312, f^2 = .120). Path coefficients of Strategy towards Ability and Fear were again ideal with large to medium effects sizes respectively (Ability: β = .442, f^2 = .203, Fear: β = .389, f^2 = .151).

Multicollinearity was again assessed to satisfy model constraints of the SEM structure. The value of multicollinearity came in at 1.016 AVIF, this being well under 3.3, and at 1.451 AFVIF, which is also ideal.

Control affect of gender

The Kruskal-Wallis test showed that Intent (intent to use a learning comic) was significantly different among males and females. The factor of Intent is significantly different between the two groups, as the effect size (f^2) is .092, which means that 9 % of the effect of whether a participant uses a comic to learn programming can be explained by gender.

a. Kruskal Wallis Test

b. Grouping Variable: Gender

Table 6.30 shows that the SPSS output for gender has a significant value of .020 ($p <. 05$). Moderating as well as control variables were found for the comic SEM.

Moderating effect of age

Age is hypothesised to significantly moderate the effects of the Subjective Norm on Intent. The results support H7c (Age on Subjective Norm-Ability, B = .281, f^2 = .091, p = .010).

TABLE 6.28: Structural model parameters for comics

Path	B	p-value	f^2	Hypotheses
Attitudes towards learning with comics				
Ability->Intent	.468	<.001	.233	H1c: supported
Subjective Norm->Ability	.312	<.001	.120	H2c: supported
Strategy->Ability	.442	<.001	.203	H3c: supported
Strategy->Fear	.389	<.001	.151	H4c: supported
Subjective Norm->Strategy	.409	<.001	.167	H6c: supported
Gender control effects:				
Gender->Intent	.276	.011	.090	H5c: supported
Age moderating effects:				
Age->Subjective Norm-Ability	.281	.010	.091	H7c: supported
R^2 = .264, Adjusted R^2 = .242				

TABLE 6.29: Kruskal-Wallis output for impacts of gender upon intent

Ranks	Gender	N	Mean Rank
Comic Intent	female	38	26.17
	male	21	36.93
Total	59		

TABLE 6.30: Output for control variable of gender

Test Statistics	Comic Intent
Chi-Square	5.378
Df	1
Asymp. Sig.	.020

The moderating effect is small to medium even though significant. It would therefore appear that age has some impact on the relationship between Subjective Norm and Personal Ability. One possible explanation of this effect could be that as a student's age increases, the less impact the friends, parents and family would have over their choice of how they might learn.

The quantitative analysis of comics and pictures is now finalised. The effects will now be incorporated into the theories that the study is based on, starting with the revised design of the technology acceptance model as part of the findings.

6.1.10 Resulting technology acceptance model analysis

The characteristics of TAMs have been used within TOAOCP to measure whether a participant would choose a comic or a picture to learn computer programming. Both TAM models were revised separately, one to suit pictures and one to suit comics. Separate models were necessary because the factors for pictures and comics loaded differently, that is, they measure different elements of design.

Pictures are concerned with form as a design element and access a different area of the brain to that accessed by comics. Order and layout are design elements that concern comics. Fun and Enjoyment loaded as a very specific factor when constructing the model for pictures, whereas the same items did not load specifically into one factor for the comic model. The way the characteristics for TAMs loaded during the EFA was a strong indicator of how students want to use different design elements and in what ways. Fun was not seen as a factor worth considering by the students in their assessment of their Intent to use comics. However, order and cognition ended up being quite significant in the comic study. The resulting TAMs are represented in Figure 6.13 and Figure 6.14.

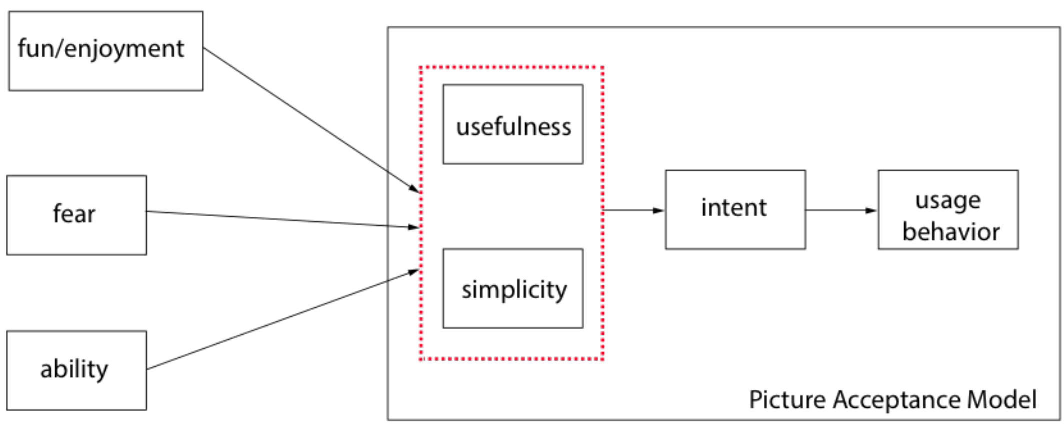


FIGURE 6.13: TAM that predicts usage of pictures to learn programming

Within the picture modified TAM model, Simplicity and Usefulness loaded into a single factor that indicates they may be measuring the same underlying factor. Here Usefulness and Simplicity may represent Perceived Usefulness PU or Perceived Ease of Use PEOU respectively and these loaded into the same construct.

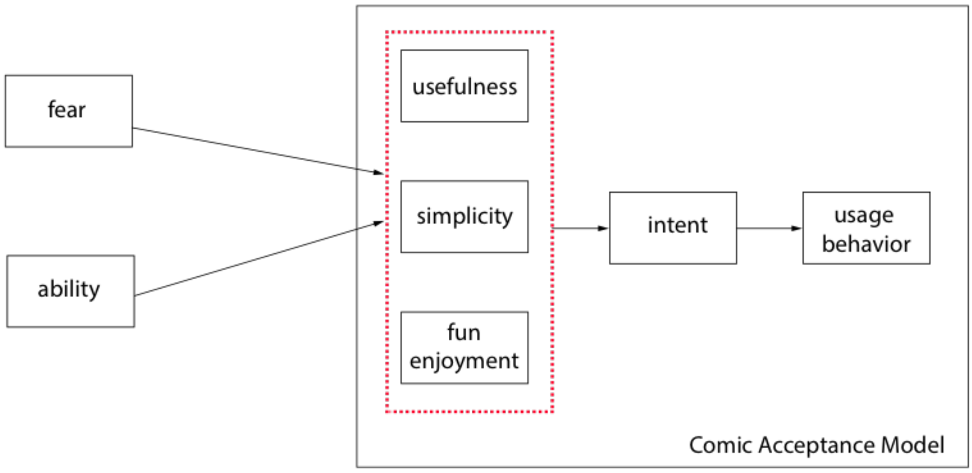


FIGURE 6.14: TAM that predicts usage of a learning comic in programming

Within the comic modified TAM, Usefulness, Simplicity and Fun/enjoyment were not separate factors. The Strategy factor emerged for comics in a similar way that Factor 1 emerged in the picture factors. Factor 1 concerned visual representation and visual literacy or the recognisability of pictures. Strategy emerged as if there had been an assessment of how to navigate the visual layout of the page, whereas the representational value was more of a priority in loading with pictures. Both the factors of Strategy and Cognition reflect different design elements of sequence and form, the former addressing the *how* and the latter addressing the *what*. In this TAM, Usefulness or PU, Simplicity (PEOU) and Fun and Enjoyment loaded into the same construct.

As well as addressing the factors of pictures and comics that concern the attitudes towards them, a knowledge test (Actual Cognitive Test - ACT) was taken. The next section discusses the knowledge test (t1) within TOAOCP.

6.2 Calculating test scores from the knowledge test

The Actual Cognitive Test for TOAOCP consisted of six programming questions. The questions ranged from the topic of binary logic (Boolean Cognition); to a tree traversal exercise (Binary Tree Cognition) and finally, to an interpretation of computer geometry (LOGO Shape 1, LOGO Shape 2, LOGO Shape 3). Table 6.31 is a summary of the six questions and the programming languages that were used in the questions.

TABLE 6.31: Six cognitive questions within the instrumentation

	Design	Computing	Language
Boolean Cognition	Spatial-Map-Path Drawing-Realism Dual Coding	Binary Logic	Swift
Function Cognition	Dual Coding	Subroutines Abstraction	JAVA
Binary Tree Cognition	Spatial-Map-Path	Tree traversal	LOGO
LOGO Shape 1	Dual Coding-External Representation-Small Multiples	Computer Geometry	LOGO
LOGO Shape 2	Small Multiples Dual Coding-External Small Multiples	Computer Geometry	LOGO
LOGO Shape 3	Dual Coding-External Representation-Small Multiples	Computer Geometry	LOGO

The values for the items were numeric and missing values were coded with a value of 99 within SPSS. The marking key for the Actual Cognitive Test (t1) within the instrumentation is as follows:

TABLE 6.32: Marking key for Actual Cognition (t1) within the instrumentation

Item	Marking Key
Boolean Cognition	B
Function Cognition	A
Binary Tree Cognition	A
LOGO Shape 1	1
LOGO Shape 2	3
LOGO Shape 3	2

To process the data collected within the instrumentation, the item values were recoded in SPSS to integers. The value for A = 1, B = 2 and C= 3, so the marking key became: (2,1,1,1,3,2). New variables were created by recoding the following items; Boolean Cognition, Function Cognition and Binary Tree Cognition into numeric variables.

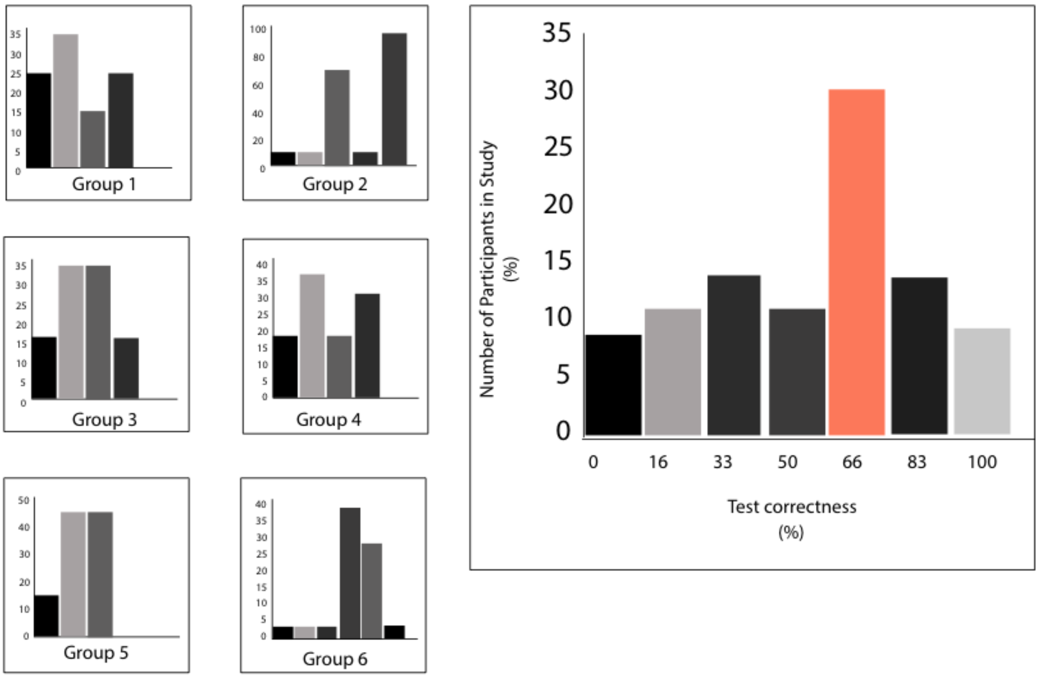


FIGURE 6.15: Breakdown of the knowledge test (t1) by group and total

6.2.1 Results of the knowledge test

Overall most scores fell within the 66% range (see Table 6.34). Figure 6.15 shows the Actual Cognitive Test (t1) scores by school and also shows a summary of the total scores overall. The majority of students scored around the 70 % mark for the learning comic. It would seem that learning comics are a good place to begin one's training for complex technical documentation. By the introduction of visual communication into a computer science curriculum, a common conversation can be started about meaning and complex topics that are represented by pictures and comics. A learning comic also allows for a focus upon what to begin learning about programming and a teacher can teach many students at the same time (when the comic is displayed at the front of the class), rather than having to address each concern of the students individually.

6.2.2 Perceived cognition verses actual cognition

The results from Perceived Picture Cognition (Evaluation Picture Factor 3) and Perceived Comic Cognition (Evaluation Comic Factor 2) were compared with Actual Cognition (Actual Cognitive Test Percentage - ACTP) separately. The Perceived Picture Cognition (PPC) and Perceived Comic Cognition (PCC) were both converted to a score out of 100. I

TABLE 6.33: Analysis of knowledge transfer by group

Test Cognition Percentage

Group			**Frequency**	**Percent**	**Valid Percent**	**Cumulative Percent**
1.00	Valid	.00	3	25.0	25.0	25.0
		16.67	4	33.3	33.3	58.3
		33.33	2	16.7	16.7	75.0
		50.00	3	25.0	25.0	100.0
		Total	12	100.0	100.0	
2.00	Valid	33.33	1	10.0	10.0	10.0
		50.00	1	10.0	10.0	20.0
		66.67	7	70.0	70.0	90.0
		100.00	1	10.0	10.0	100.0
		Total	10	100.0	100.0	
3.00	Valid	33.33	1	16.7	16.7	16.7
		66.67	2	33.3	33.3	50.0
		83.33	2	33.3	33.3	83.3
		100.00	1	16.7	16.7	100.0
		Total	6	100.0	100.0	
4.00	Valid	50.00	2	18.2	18.2	18.2
		66.67	4	36.4	36.4	54.5
		83.33	2	18.2	18.2	72.7
		100.00	3	27.3	27.3	100.0
		Total	11	100.0	100.0	
5.00	Valid	.00	1	14.3	14.3	14.3
		16.67	3	42.9	42.9	57.1
		33.33	3	42.9	42.9	100.0
		Total	7	100.0	100.0	
7.00	Valid	.00	1	7.7	7.7	7.7
		33.33	1	7.7	7.7	15.4
		50.00	1	7.7	7.7	23.1
		66.67	5	38.5	38.5	61.5
		83.33	4	30.8	30.8	92.3
		100.00	1	7.7	7.7	100.0
		Total	13	100.0	100.0	

TABLE 6.34: Actual Cognitive Test (t1) total score breakdown

Actual Cognitive Test Percentage

Group		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	.00	5	8.5	8.5	8.5
	16.67	7	11.9	11.9	20.3
	33.33	8	13.6	13.6	33.9
	50.00	7	11.9	11.9	45.8
	66.67	18	30.5	30.5	76.3
	83.33	8	13.6	13.6	89.8
	100.00	6	10.2	10.2	100.0
	Total	59	100.0	100.0	100.0

then took the mean of the two perceived cognition scores together to give me the Total Perceived Cognition (TPC) and compared it again with the Actual Cognition Test Percentage (ACTP). The paired T-test was used for this experiment and the results are listed in Table 6.35.

TABLE 6.35: SAC verses ACTP by total, comic and picture

Paired T-test		Df	Sig. (2-tailed)
Pair 1	Total Perceived Cognition – Actual Cognitive Test Percentage	58	.035
Pair 2	Perceived Picture Cognition – Actual Cognitive Test Percentage	58	.003
Pair 3	Perceived Comic Cognition – Actual Cognitive Test Percentage	58	.283

There was a significant difference between the participant's perceived cognition and their actual cognition. Individually the perceived understanding of pictures (PPC) was significant while their perceived understanding of comics (PCC) was not significant. The difference between Perceived Cognition and Actual Cognition has been defined and addressed in detail within the literature review (see Section 4.5.4). The participant's perception of understanding pictures or Perceived Cognition (t3) was higher than their actual understanding (test score, t1). The participants' Total Perceived Cognition (TPC) of the curriculum was significantly higher than their Actual Cognition (ACTP). TPC is the combined perceived cognition score from both pictures and comics.

Structural equation modelling (SEM) is used in social science experiments to predict certain variables from others. Relationships can be exposed within SEM between latent variables, which cannot ordinarily be seen from observed variables. This allows a hypothesis to be established that a construct, such as Self-Assessed Cognition, can be inferred from another construct like Actual Cognition. The observed variables of the test score (Actual Cognitive Test Percentage) were modelled to the participant's perceived cognition of pictures and the comics (PPC, PCC). These models can be viewed in figures 6.16 to 6.18.

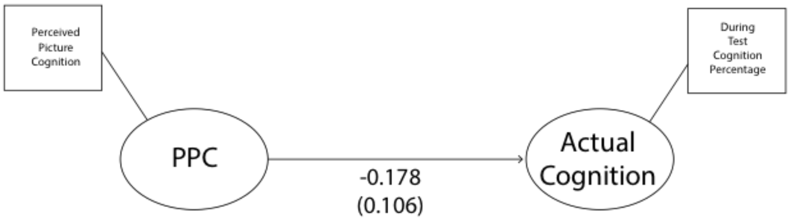


FIGURE 6.16: Regression analysis of Perceived Picture Cognition on Actual Cognition

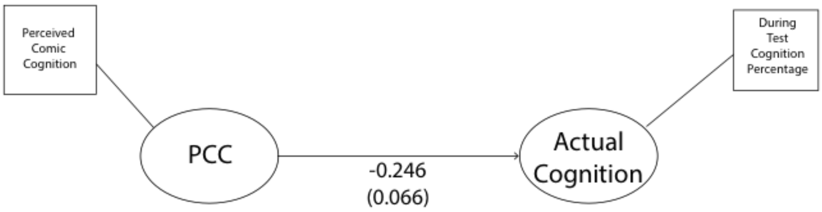


FIGURE 6.17: Regression analysis of Perceived Comic Cognition and Actual Cognition

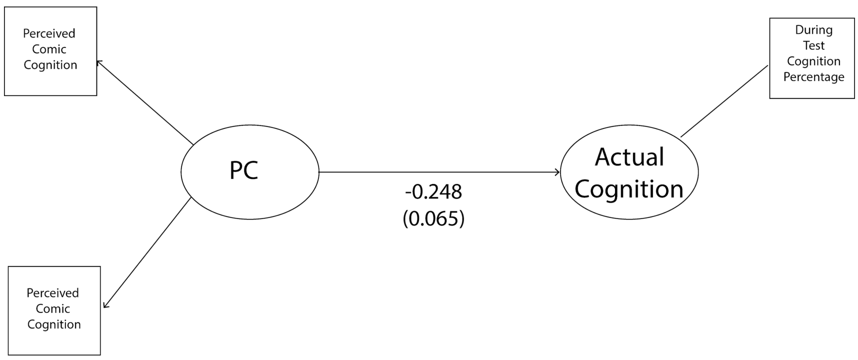


FIGURE 6.18: Regression analysis of the Total Perceived Cognition and the Actual Cognition

The perception of understanding pictures and comics was then compared with the actual understanding. Structural equation modelling was used to measure the relationship between the perceived cognition and Actual Cognition. This showed no significant relationships.

6.2.3 Cognitive effect of pictures

Picture effectiveness is the sum of the number of correct answers for each question and produces the effect of the graphic design. Algebraically, in TOAOCP picture effectiveness can be written as:

PE q = Sum(TS n + TS n +1)

- Where PE = Picture Effectiveness
- TS = Test Score for each participant
- q = the question concerned
- n = the number of participants

The most effective or most understood question was the questions on LOGO in the instrumentation, while the questions on subroutines, Boolean logic and binary trees were the least correctly interpreted. This method of calculating the cognitive effect of the pictures within the curriculum could be used as a measure of how effective a picture is, as this is a calculated score that can be automated within the instrumentation. Once the person teaching the curriculum analyses this score, the curriculum can be altered to increase the picture effectiveness. For example, if the subroutine or function question is scoring low for picture effectiveness then the students could be asked how the picture could be made better, or the students could even be given the task to draw the exercise themselves. The educator could therefore alter the curriculum until an increase in effectiveness was obtained or the effectiveness at least reached a minimum threshold.

TABLE 6.36: Descriptive statistics for the Actual Cognition (t1)

Descriptive Statistics

	N	Sum
Test Score Function	58	210.00
Test Score Boolean	54	240.00
Test Score Binary Tree	51	330.00
Test Score LOGO Shape 3	49	350.00
Test Score LOGO Shape 2	49	370.00
Test Score LOGO Shape 1	47	420.00
Valid N (listwise)	37	

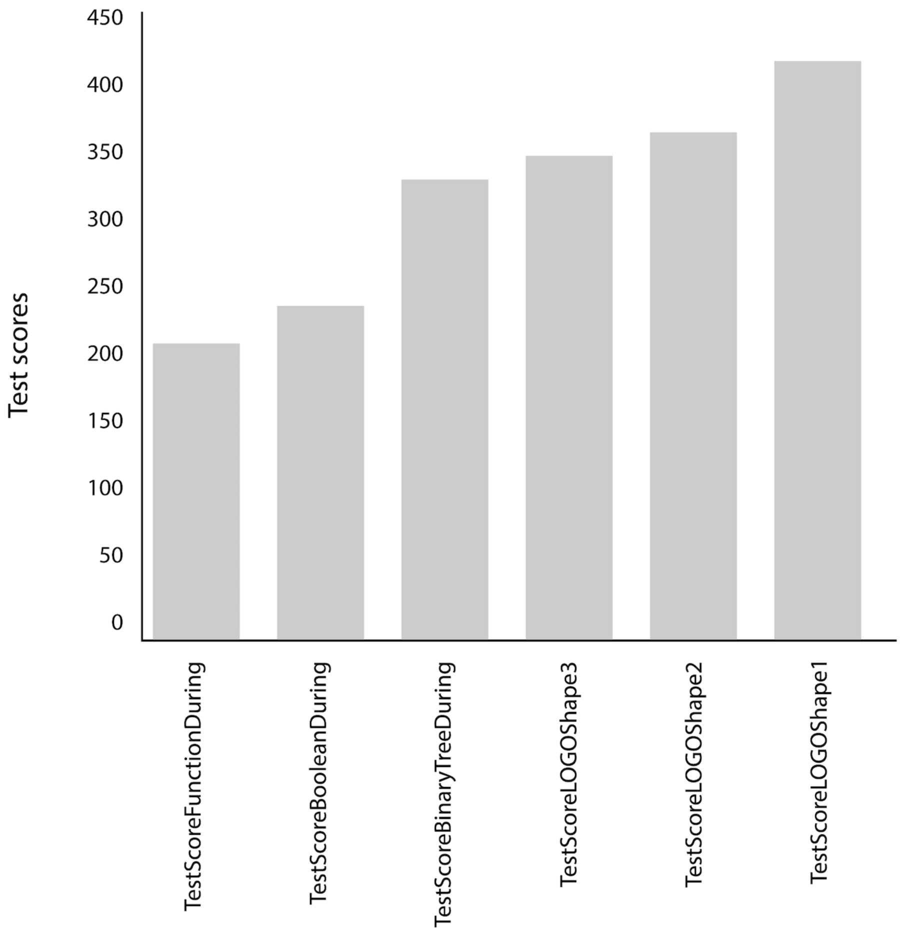


FIGURE 6.19: Graph of picture effectiveness for each question

6.2.4 The role of pictures within learning computer programming

A final examination of the data collected from the role of pictures in programming is now summarised. The participants were surveyed at the beginning of the data collection in order to gauge their understanding of what pictures were used for. It appears most of the students surveyed believe pictures are predominantly used within an artefact for aesthetic or quick communication purposes only. The result from the data is shown in Figure 6.20.

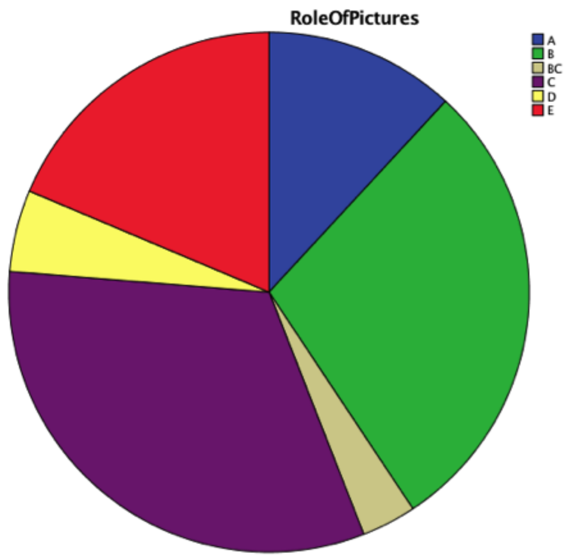


FIGURE 6.20: SPSS output: The role of pictures in learning programming. The blue colour represents meaning-making, green represents aesthetics and purple represents communication. The red and yellow colours represent the blank answers and also a "none of these" answer respectively. Meaning-making was the least selected as an answer.

There seems to be no processing of pictures occurring beyond instant recognition. A further breakdown by gender revealed the following graphs in Figure 6.21 to Figure 6.22.

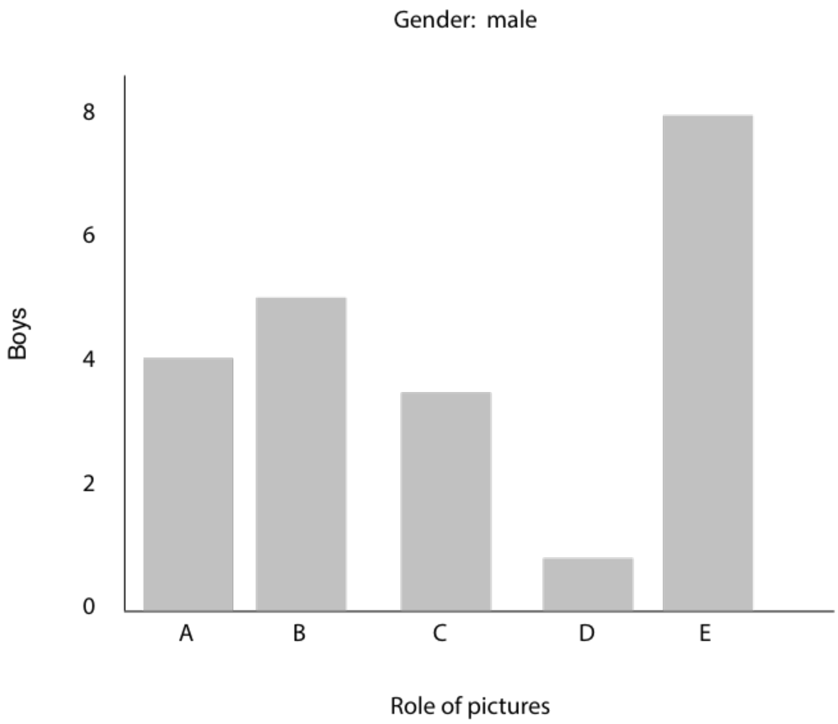


FIGURE 6.21: Male understanding of the role of pictures in learning. The column A represents meaning-making, B represents aesthetics, C represents fast communication and D and E were "none of these" or blank answers.

Aesthetics was the highest factor given by the males, followed by meaning-making and then communication. Males were more likely to consider a picture as being a 'thing' that means something else over the females. That is, they rated meaning-making higher although there was still a high score for pictures being included for their aesthetic value.

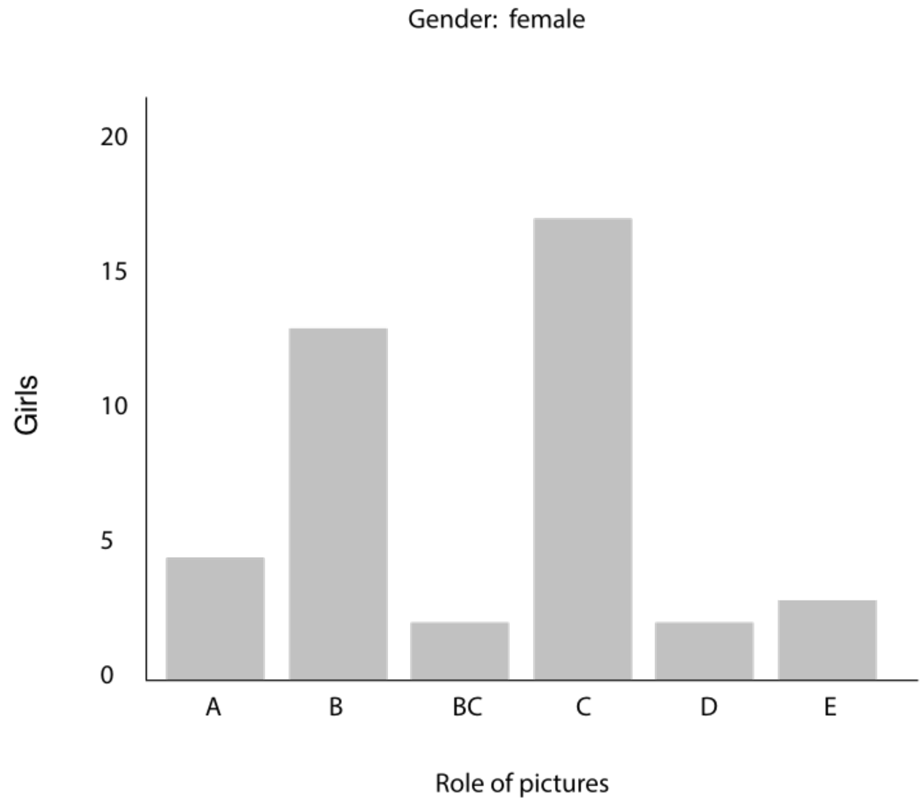


FIGURE 6.22: Female understanding of the role of pictures in learning

The same values apply to the axis as for the male graph above. In Figure 6.22 the females believed quick communication to be the reason that pictures are used to learn computer programming. Aesthetics was the second highest selected reason and meaning-making was last.

Surprisingly this trend where meaning-making did not rank as highly as aesthetics was reversed in the pilot study. The primary school participants gave meaning-making a high score and rated aesthetics last. This is an interesting trend that is worthy of future examination,as the question could be asked - at what stage in a student's education does this trend of pictures being used as a meaning-making tool change to pictures being seen as only having aesthetic value? This concludes the results of the quantitative analysis and the study will now move into an analysis of the qualitative data which begins with an analysis of each focus group discussion.

6.3 Qualitative analysis

A basic set of questions was formulated to use within the focus group discussion sessions from the literature review. These questions were added to after the quantitative survey took place. The focus groups were run after the quantitative data collection to gain a richer understanding of the relationships between the variables. Two focus groups were conducted with students from Year 8 information technology classes. The two schools that were open to the running of a focus group after the quantitative data collection was a single-sex female school and a co-educational school. In total twenty two students were included in the focus groups, with an average of eleven students per group. There was a balance of males and females in the second focus group however the first focus group was all female. The imbalance could have been corrected by the addition of an all male focus group. However, no private boys schools responded to participate in the study.

I facilitated the focus groups and transcribed the focus group data. A transcription service was used for purposes of validity (Glaser & Strauss, 1967) and the transcription is included as an attached file to this thesis along with the original transcriptions. Cross referencing or mediating of the two transcripts can occur for any further validity necessary. Confidentiality was included in the transcription contract in alignment with ethics requirements. Topics covered within the focus groups were based on the role of visual communication elements within a learning comic. The components featured were the intent of the picture, visual literacy and representation of the pictures, dual coding theory, interpretation of circuits, truth tables, binary tree traversal, understanding of the role of comics in learning, gamification elements and narrative design. These questions were contextualized within the topic of computer programming. During the five year course of my PhD, I performed an extensive literature search upon learning computer programming through graphic design. Very little research has been carried out upon the impacts of graphic design and learning computer programming. Despite this, the text I have found that supports the use of pictures and graphic design within the communication of computer science (see Section 7.4.5) has not been adopted widely as the standard method of documentation. The prevalence of a narrow style of linear text for programming documentation could be due to many reasons, from rapid change and uptake of new technology to the lack of skilled practitioners that work transdisciplinarily in programming and graphic design. Both the impact and the value of graphic design within the learning of programming are the focus of this research.

The focus groups were run during the first semester after the quantitative questionnaires were administered. The themes that emerged from the quantitative data analysis of Usefulness, Prior Knowledge, Fear of assessment and Intent to learn were contextualized within the subject of computer programming, that is, the questions were illustrated with computer science drawings and displayed to the focus groups as part of the discussion questions. A discussion of the results of the focus groups follows. An exploratory factor analysis that was completed during the quantitative analysis helped to establish the themes mentioned in the second sentence of this paragraph, along with the initial literature review. Any significant increases or decreases in the responses by the participants to the quantitative survey were noted and raised within the focus groups. The impacts that emerged within the focus group discussion sessions are now addressed.

6.3.1 Emerging impacts that informed the focus group discussion questions

The quantitative results were combined with the analysis of the focus group discussions to triangulate findings. This triangulation developed richer conclusions of the factors or impacts concerning visual communication and computer programming. Four emerging themes were identified for pictures and comics within the TAM quantitative data (Usefulness, Fear, Intent to learn through, and finally Prior Knowledge of computer science) and one solely for pictures (Fun and Enjoyment) during the quantitative analysis. Aggregate-level data is data that is summed from a set of variables (see Section 6.1.3). An aggregate is formed by combining variables. In TOAOCP, Attitudes (see Chapter 4, Section 4.5.1) is an aggregate variable. The variables are summed by the researcher within SPSS to obtain the summed aggregate variable. When the Attitudes impacts, Usefulness, Simplicity, Fun and Enjoyment, Fear and Personal Ability were combined at aggregate level, they had a positive impact upon the intent to learn computer programming through visual communication.

In order to establish focus group discussion questions in addition to those initially established from the literature review, the individual impacts established from the exploratory factor analysis (EFA) in the quantitative analysis also informed development of the focus group discussion questions. The impacts were Usefulness of both pictures and comics, Fear of understanding pictures and comics, Intent to learn through both pictures and comics, and finally Prior Knowledge of computer science. Fun and Enjoyment of learning emerged as a factor on its own under pictures but not solely under comics due to the convergence of the factors Fun, Usefulness and Simplicity together. There appears to be more of a sustained learning focus and engagement with the use of the comic. Sustained engagement comes from looking at picture after picture without considering the navigation of the lesson or 'where do I look next?' In the quantitative study (see Section 6.1.3), comics were treated as a serious learning tool by the participants and Usefulness and Simplicity were prioritised above Fun and Enjoyment. The priority of Usefulness and Simplicity of the participants over Fun and Enjoyment by comics when learning computer programming could mean that comics were seen as a device that reduced cognitive load. While the quantitative study established pictures as being fun, pictures in sequence were prioritised by the participants as a pedagogical tool as Useful and Simple as opposed to Fun and Enjoyment.

These impacts are discussed in the following paragraphs connected to the relevant literature and participant responses from the focus groups. During the analysis of the qualitative data, NVivo software was used to tag the constructs identified in the quantitative analysis. The following image, in Figure 6.23 is an output generated from NVivo after running a word count on the memos I kept on discussions of two of the focus groups. Figure 6.23 represents the themes and the frequency of word presence within the discussion group transcripts. The nodes within NVivo were labelled thematically to reflect the topics that arose in the transcripts. The coded themes or nodes are listed in Table 6.37.

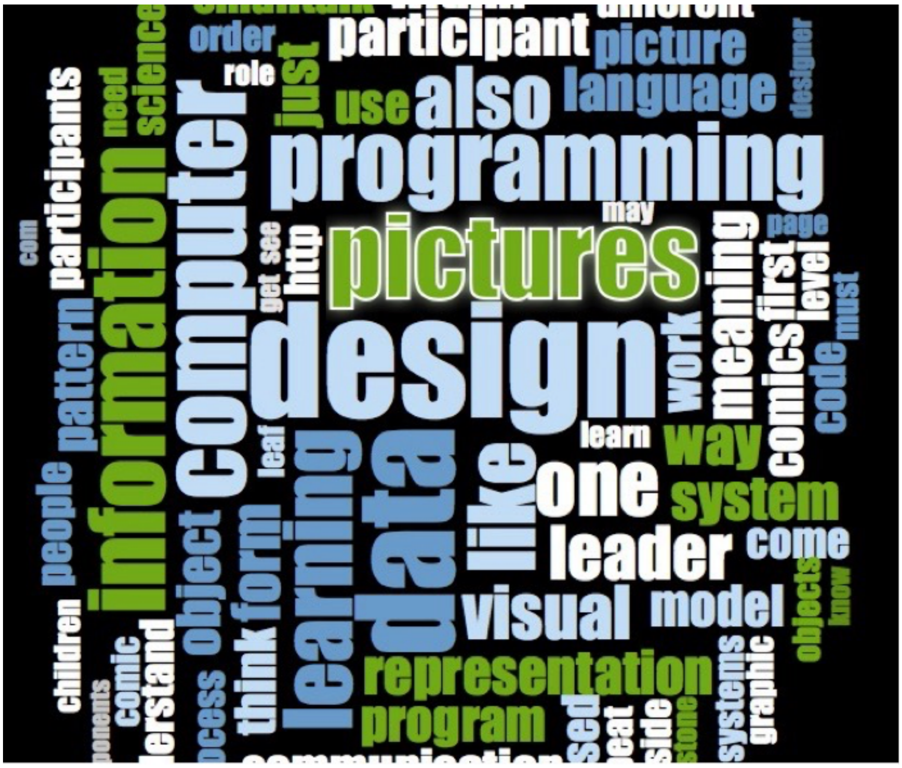


FIGURE 6.23: Word cluster analysis from NVivo focus groups

TABLE 6.37: NVivo nodes and coded references in order of frequency

Node in NVivo		Number of References	
Meaning-making Sources: 2 focus groups	rhetoric	22	
Miscellaneous		40	
Cognitive load Sources: 2 focus groups	Comic Sources: 1 focus group	15	2
	Gamification Sources: 1 focus group		2
	Pictures Sources: 1 focus group		1
Aesthetics Sources: 2 focus groups		14	

continued . . .

...continued

Node in NVivo		Number of References	
Learning visual communication Sources: 1 focus groups		12	
Fear of assessment Sources: 2 focus groups		10	
Learning Fear of misinterpretation Sources: 1 focus groups		10	
Co-design co creation Sources: 2 focus groups		9	
Gamification Sources: 2 focus groups	Fear of scoring Sources: 2 focus groups	9	8
	No fear of scoring Sources: 2 focus groups		2
Narrative design Sources: 2 focus groups		9	
Layout and dual coding Sources: 1 focus group	issues	8	
Peaked energy Sources: 1 focus group		8	
Ease of use comics Sources: 2 focus groups		7	
Ease of use pictures Sources: 1 focus group		7	
Fun enjoyment of pictures Sources: 2 focus groups		7	
Mental models Sources: 1 focus group		4	
Prior knowledge Sources: 1 focus group	Pictures 1 focus group	4	3
	Programming 1 focus group		2
	Comics 1 focus group		1

continued ...

...continued

Node in NVivo		**Number of References**	
Linguistic communication Sources: 2 focus groups		1	
Fun enjoyment of comics Sources: 2 focus groups		2	
Graphic design agency Sources: 2 focus groups		2	
Communication Sources: 2 focus groups		1	
Intent Sources: 2 focus groups	Intent to learn through comics	1	3
Learning comic Sources: 2 focus groups		1	
Pattern searching Sources: 2 focus groups		1	
Usefulness of pictures Sources: 2 focus groups		1	
Video learning Sources: 2 focus groups		1	

The two focus group transcriptions were coded after they were imported into NVivo. Coding is a process where themes concerning the research questions are examined for how often they come up within the data collected. Initially, the constructs that emerged from the quantitative analysis were created as nodes in NVivo. A node is a container that stores the coded information by theme. For example, any comment made about the topic of aesthetics was stored within the aesthetics node. The figure below shows the nodes compared to the number of coding references. Meaning-making appears to be highly coded, in other words this was a topic that attracted a lot of discussion, whereas communication does not seem to have as many references made to it within the focus groups.

6.3.2 Meaning-making: The role of pictures in learning

The theme of the role of pictures in learning was reviewed in the focus group discussion questions in order to triangulate the responses gathered in page four of the quantitative instrumentation (see Appendix A; see also Figure 6.24).

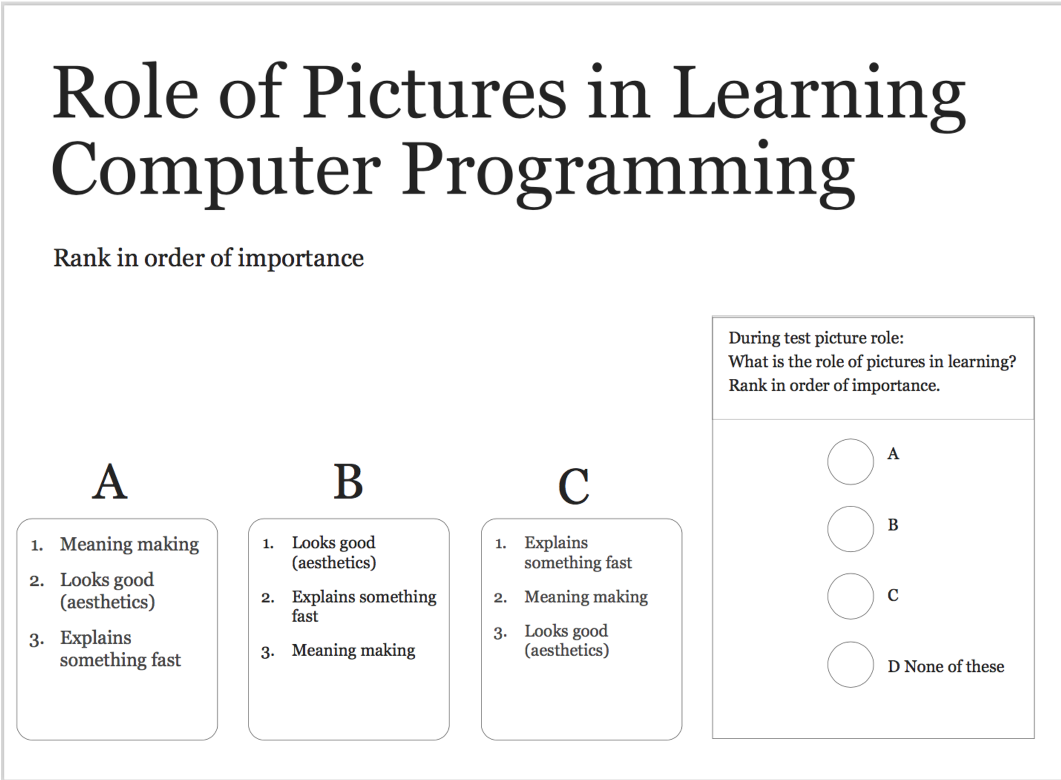


FIGURE 6.24: Page four of quantitative instrumentation

As can be seen from Table 6.37, the participant references to meaning-making were 22 in number and aesthetics were 14 in number. That far exceeded the participant references to communication that were only one in number. The meaning-making question (role of pictures in learning) in the survey, and the focus group discussion questions were designed to gauge the level of rhetorical awareness of the participants (see Appendix A). The first group were engaged in understanding the difference between aesthetic pictures and pictures that are used more with a purpose for meaning-making. As a response to the participants' enquiries, I suggested to the participants that some types of pictures such as Figure 6.26 may be more suitable to learn computer programming from than other types (see Figure 6.27 and 6.28). Although an intent to learn programming through pictures was established through the quantitative models in Section 6.1.9, the participants regarded the role of pictures in learning as aesthetic and communicative in contrast to meaning-making (see Figure 6.25) or those suited to a pedagogical role.

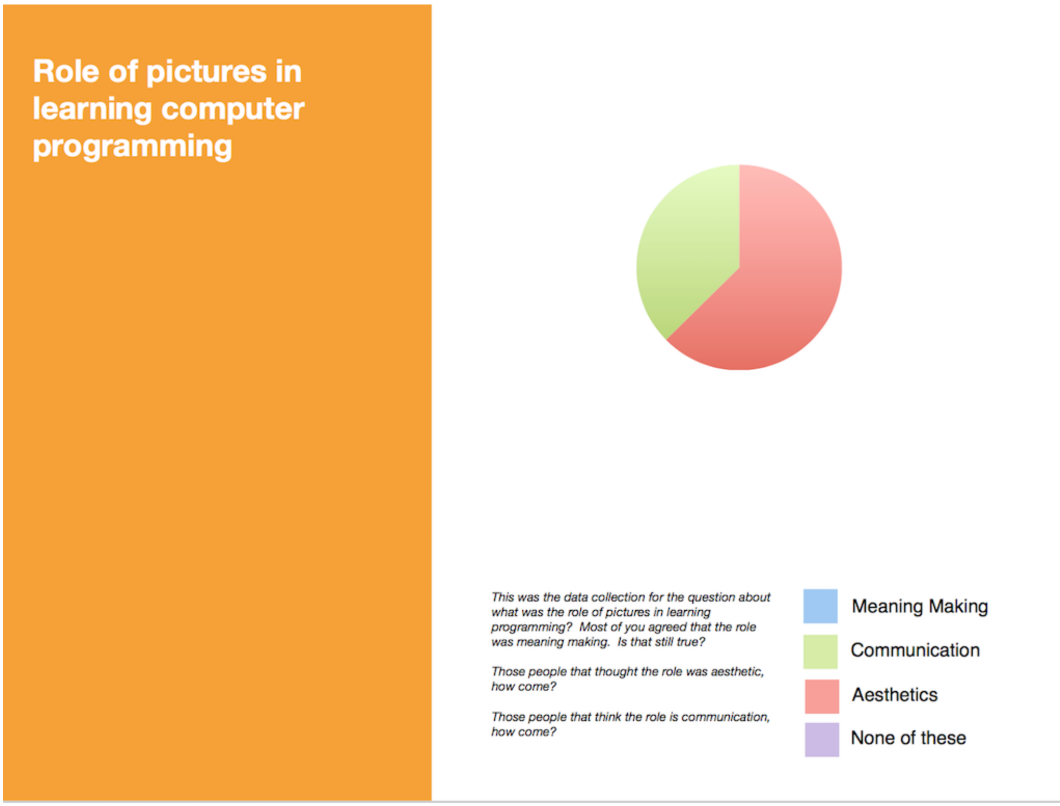


FIGURE 6.25: Role of pictures in learning: results for the first focus group

Throughout the instrumentation in TOAOCP I had used pictures as cognitive artefacts in contrast to the iconology used in communication design and the aesthetic pictures often used in the discipline of visual art. As the focus group participants had scant visual literacy training, I displayed the Figures 6.26 to Figure 6.28 and used these as prompts to solicit deeper information on the nature of how pictures are used.

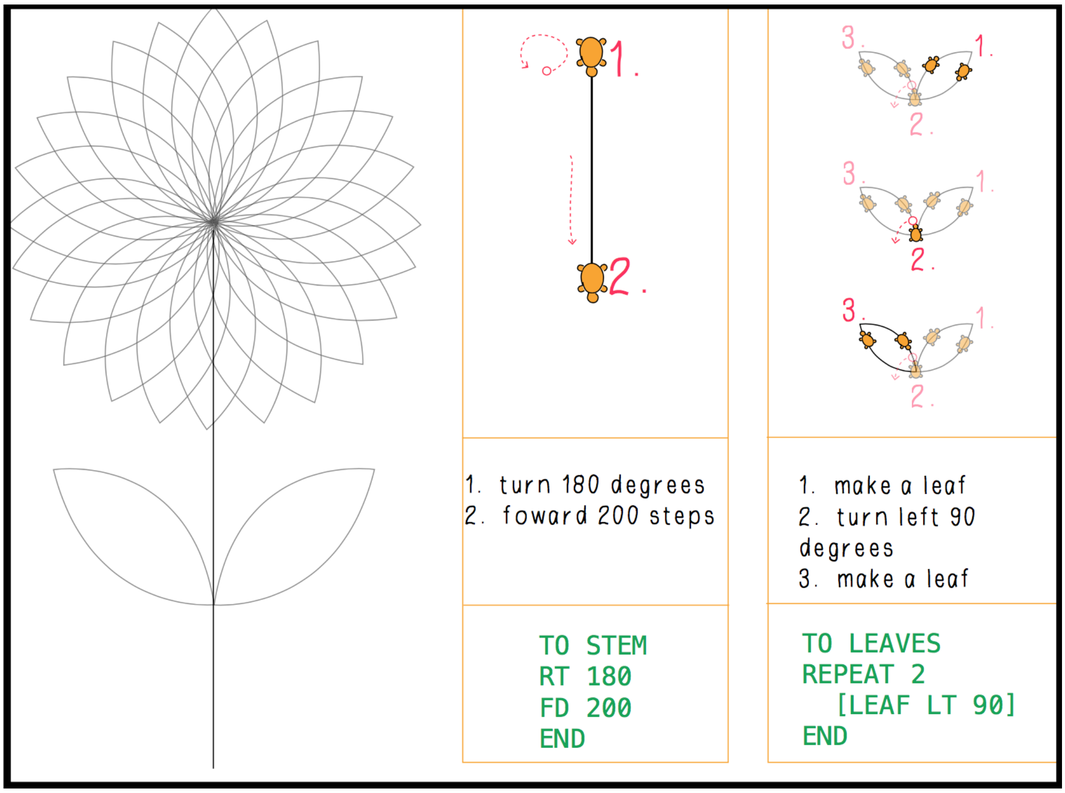


FIGURE 6.26: Page three of focus group discussion questions

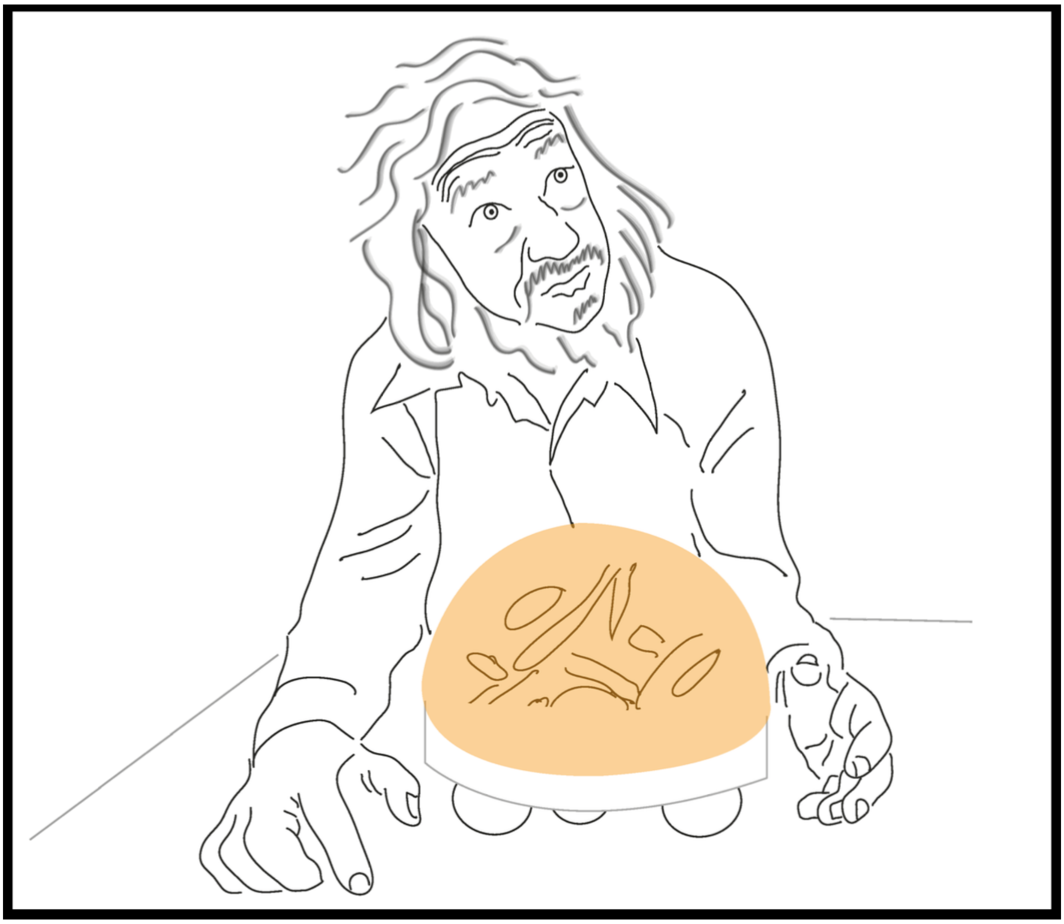


FIGURE 6.27: Page four of focus group discussion questions

FIGURE 6.28: Page five of focus group discussion questions

There was an acceptance about meaning-making among the first focus group as well as an enthusiasm to understand more about the differing roles of pictures in learning. The second focus group simply accepted meaning-making as being the role of pictures in learning. An initial analysis of the data gathered from primary school children in year six revealed that meaning-making was also the role of pictures in learning (see Section 6.2.4). The trend or role of pictures in high school was aesthetics in contrast with the trend in primary school. Section 4.3.8 has discussed how society reverts to appearance when systems are in conflict or difficult to understand. Papert's principle, first documented by Minsky in his book, *The Society of Mind*, has been used within TOAOCP to explain the phenomena of why pictures were mostly viewed as aesthetic or decorative by the participants (Minsky, 1988).

As well as discussing meaning-making as the role of pictures in learning, meaning-making was at times addressed by the participants throughout the focus groups. There were many mentions made of what the pictures were meaning, and of the layout of some of the information that was presented within the instrumentation. Comments concerning clarification of the pictures or the layout of the comic were made in the focus groups discussions. There were also moments of clarity accompanied with increased energy when meaning-making occurred. Comments included "... I've got it ....OK" and "So it's like a sum" and "Oh Yeah ... the circle". Meaning-making was on the whole associated with positivity. However, there was also active discussion around how to make the visuals clearer with comments such as "Oh... a bit confused" and "Yeah so it's kind of like a specific order, it creates order." These sorts of comments indicate that there was a general willingness to get the visual communication correct or agreed upon.

Meaning-making had the highest number of coded entries not only because of the specific question asked at the focus groups on the role of pictures in learning, but also because of the priority of the participants to understand the pictures and their associated sequences. The high number of references to meaning-making may also indicate a need for the participants to be involved in the actual design process itself, of visual pedagogy for learning computer programming. The next highest number of coded references within the focus groups was about the cognitive load.

6.3.3 Cognitive load

The qualitative content of the focus groups was informed by the quantitative analysis. Cognitive load was featured in the quantitative analysis in Section 6.3.1 because of the participant's prioritising of Usefulness (item 1.3 Appendix C) and Simplicity (item 1.5 Appendix C) when using the learning comic. In the focus groups, a high number of comments were made regarding reading and the lessening of contextual confusion through using comics and pictures. In an initial statement a participant remarked that with instructions, the visual communication used in the instrumentation was highly important and further stated, "It shows you how to do it and the same with sewing because reading the instruction book is just so confusing." Here, the participant was referring to a sewing book that resembled pictorial assembly instructions (PAIs). Clarification was sought, with one participant asking "Wait, when you say comics do you mean just like a picture with words?" The participant was referring to the agency or choices of the comics creator concerning the amount of words within the panels.

With regard to the circuit diagram, there was a reference to diagrams being "tricky" when labelled with letters. Reflecting the results in Section 6.1.4, some of the Simplicity and Usefulness items did not reflect an improvement in the posttest (see Appendix C). The picture effectiveness of the circuit diagram did not score very highly and was only answered about 50% correctly. One way to clarify the pictures and their associated information would be to place all the information on Figure 6.29 and Figure 6.30 onto one page instead of them residing on separate pages.

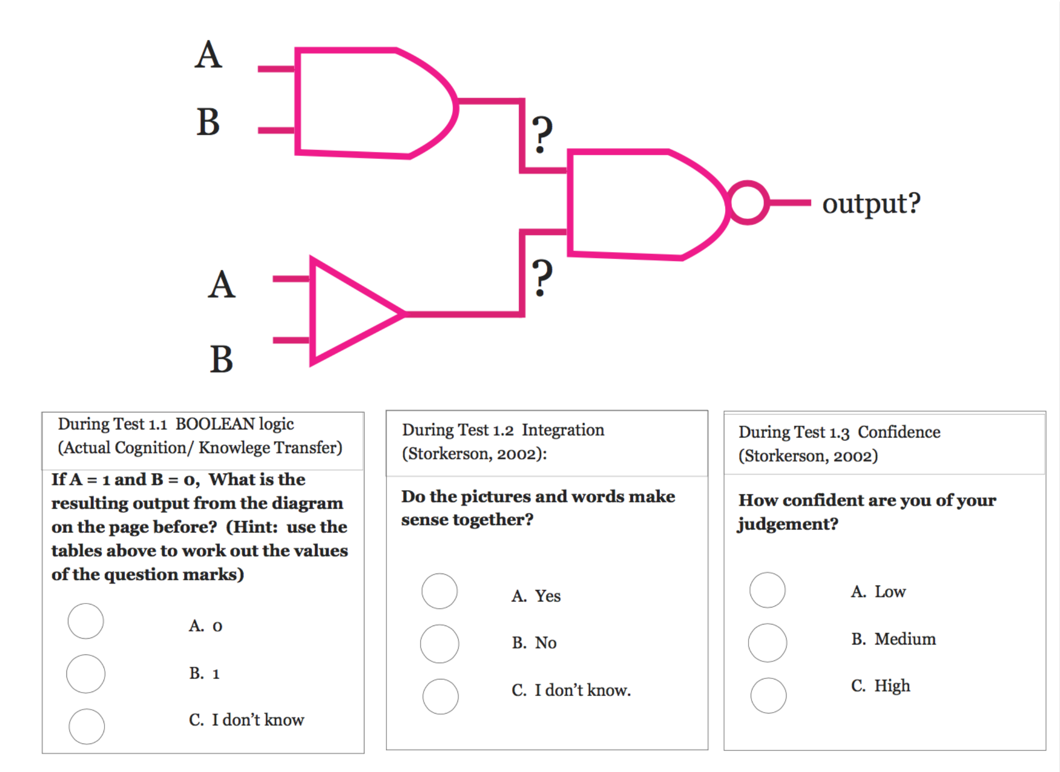
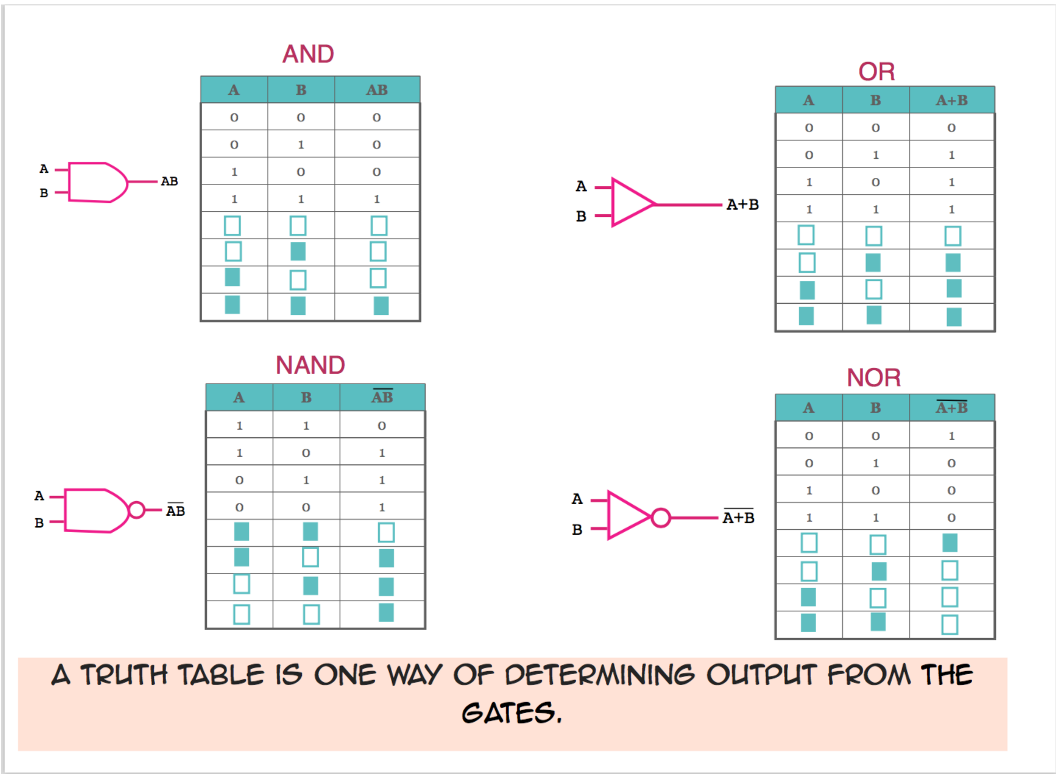


FIGURE 6.29: Page fourteen of the instrumentation



AND

A	B	AB
0	0	0
0	1	0
1	0	0
1	1	1
□	□	□
□	■	□
■	□	□
■	■	■

OR

A	B	A+B
0	0	0
0	1	1
1	0	1
1	1	1
□	□	□
□	■	■
■	□	■
■	■	■

NAND

A	B	$\overline{AB}$
1	1	0
1	0	1
0	1	1
0	0	1
■	■	□
■	□	■
□	■	■
□	□	■

NOR

A	B	$\overline{A+B}$
0	0	1
0	1	0
1	0	0
1	1	0
□	□	■
□	■	□
■	□	□
■	■	□

FIGURE 6.30: Page fifteen of the instrumentation

Participants expressed that in order to understand the pictures they could not recognise, these could be supplemented with text. They also mentioned that using more text in the descriptions of the pictures would balance any failure to recognise any contextual symbols such as those in Figure 6.29. The term 'labelling' was used by the participants. Another way to address the recognisability of the shapes in the circuit diagram would be to introduce circuit diagrams to the participants before the instrumentation. Early introduction of what pictures mean would ensure that a circuit diagram would be part of their existing or prior knowledge. In this way, the diagram I displayed to the focus groups, may not been seen as a "tricky question".

6.3.4 Aesthetics

In the focus groups, in order to get more information concerning the results of the role aesthetics plays in participants' learning, their quantitative results were shown to them (see Figures 6.31 and Figures 6.32).

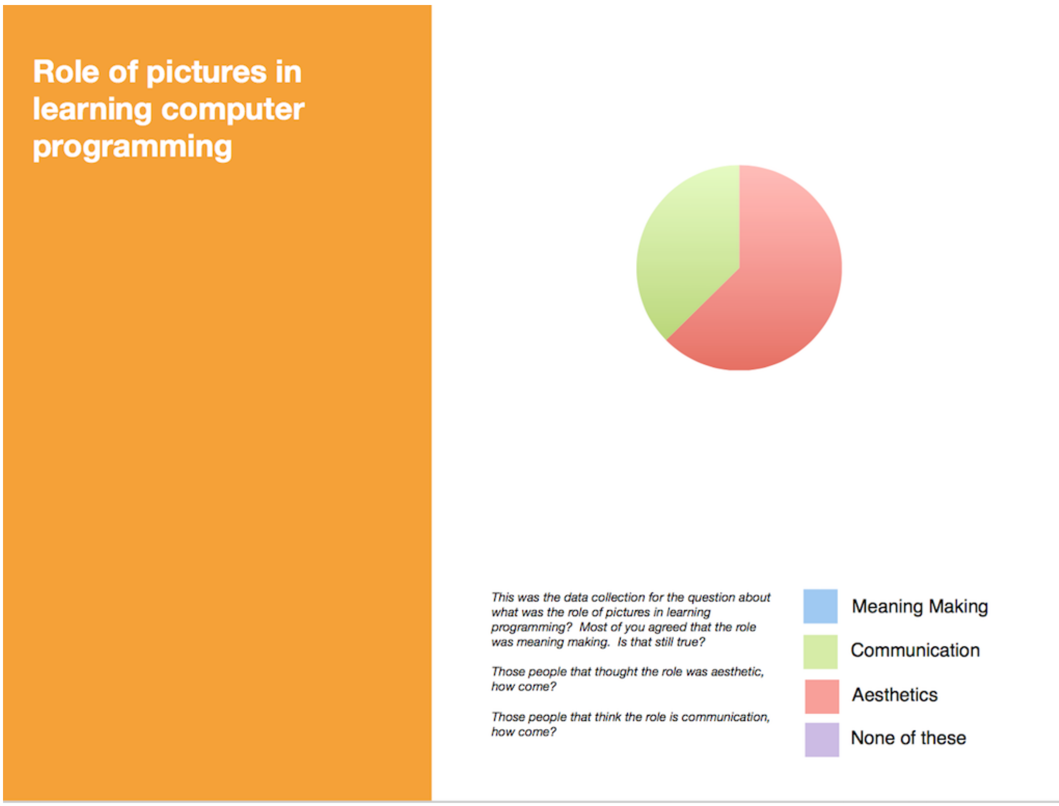


FIGURE 6.31: Results of the role of pictures in learning from the quantitative analysis shown in the first focus group discussion

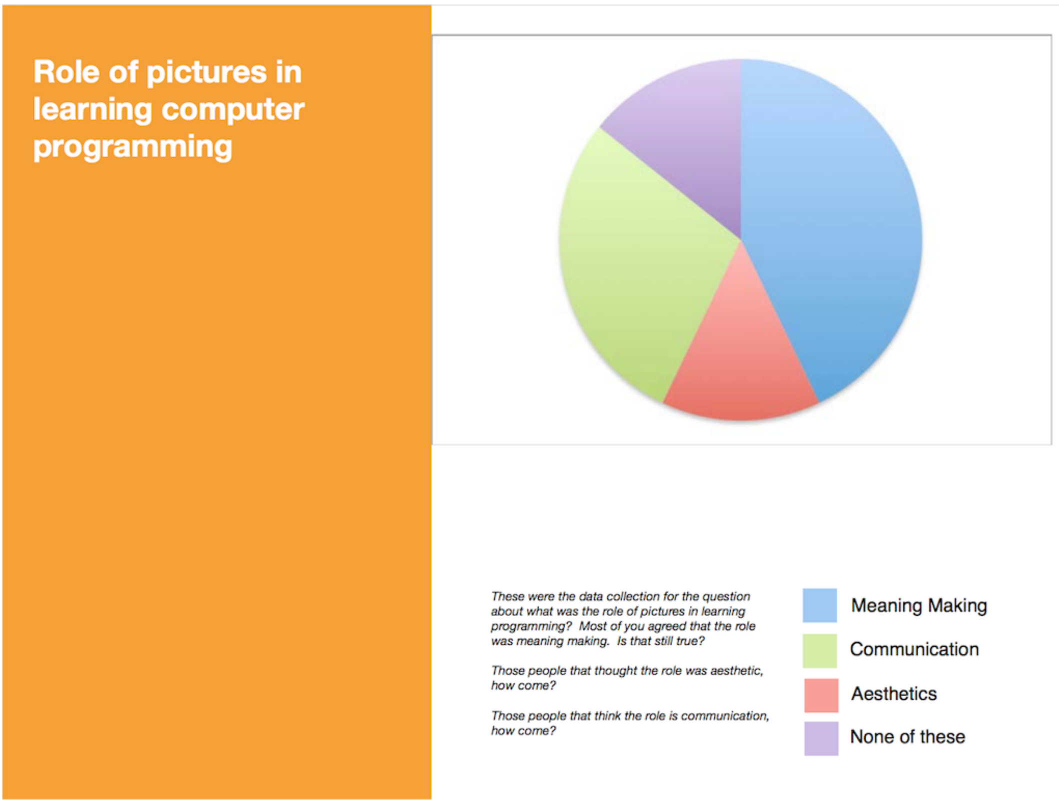


FIGURE 6.32: Results of the role of pictures from the quantitative analysis from the first group

Aesthetics was also highly coded throughout the qualitative analysis, beginning with a picture's role within learning (see Section 6.2.4). Pictures were predominantly thought of as aesthetic across all seven groups in the quantitative study and the first focus group. When asked about the definition of aesthetics the participants volunteered that the picture was "Pretty, looks good", "Because it looks nice" and agreed that when something was "well drawn" it was aesthetic.

Participants were unclear about how or why a picture or comic was aesthetic, just that it may hold a viewer's gaze so that attention was focused upon it. I was asked to clarify my understanding of aesthetics in comparison to meaning-making, and my explanation to the students in the first group created a strong focus and a positive response to learning: In response to the participants' request, I again showed Figures 6.28 to Figures 6.26 and explained to the participants that for TOAOCP, I had created some pictures for aesthetic purposes and some for learning programming. I also explained that there was a difference between a picture like the Mona Lisa which is an artwork, and a map displaying a direction to travel. The idea of learning through visual communication also coded highly within the focus group sessions.

6.3.5 Learning visual communication

Remarks from the students support the idea that visual communication for them is "a different way to understand". There was initial confusion among the participants, especially with certain types of diagrams they had not seen before. Statements were made by the particpants in the focus group discussions, such as "I didn't totally get it if it was the shape, AND or NAND or whatever". The design of the binary circuit component in the lesson confused a few students because the information was expressed over more than one page. The students believed the information should not be on separate pages but should all be on the same page. In other words, the organisation of tables and pictures for the binary circuit should all be together. The confusion here reflects the quantitative results of Section 6.1.4 in that although they believed they would be able to use visual communication to learn with and that it would be easy, some items for the factors of Simplicity and Usefulness decreased in the posttest. Although participants thought they would be good at visual learning, initially they were not used to learning through visual communication. This supports the importance of careful layout design in the development of visual communication materials for learning.

Overall there was a positive view concerning visual communication and learning. Participants stated that they thought the learning was "more visual and so we understand more because of the pictures and stuff".

Learning from comics was something the students agreed they would like in the future. Despite this generalisation by the focus groups, there was concern from some students about words being easier in comparison to comics and some concern with regards to the understanding of comics. Elaboration of this point was further contextualised by the group, confirming that visual communication was "...a different way of thinking". And that this "different way" was not necessarily connected to the content but the look.

6.3.6 Gamification and interactive elements

Gamification techniques discussed with the participants that could be incorporated and used within TOAOCP are summarised in this section. Gamification within TOAOCP was considered as ancillary and not included in the main picture layouts presented to the participants. The reason gamification is ancillary within TOAOCP was because when the instrumentation was designed there was limited research incorporating gamification and pictures.

Participants were involved in the design process by asking their opinion on implementing scoring within a learning comic in the focus group discussion sessions. The comments on gamification fell into three different themes or codes. There was a general theme and then separate codes setup for scoring both positive and negative towards gamification. The comments on scoring were quite specific and were given nodes in NVivo. There was piqued interest and positivity about the topic of gamification.

Different features were introduced in the focus group discussion that could be added to an artefact like the instrumentation. The poke feature was introduced early into social media as a novelty feature and remains undefined (Perez, 2017) but is generally a means of getting the attention of another user on the platform. Within TOAOCP the poke feature signalled to one student from another that they were being contacted with a "beep" sound. Delight and fun accompanied the design of the "poke" feature that I introduced to the mix from social media purely in the interest of novelty. A feature such as "poking" could be integrated to contact another participant or teacher and a sound could ring. Participants were able to evaluate both advantages and disadvantages of the poke digital feature. One participant admitted that this feature could be open to misuse stating "Yeah but that's going to be so bad". Otherwise all comments regarding the badges, messaging the teacher and poking were very positive. For example when asked about the features the answers were "Oh yeah, I'd like that so much" and "Yep I'm up for that!" However, not all comments continued with this theme in the two separate sessions.

The topic of timing and scoring within the gamification features provoked much discussion. The majority of students did not want a timer on the page, stating that it would make them feel "a bit rushed" and "I feel like it's better if we just work". One participant supported the timing idea making the remark that "... some people might work fast". Further clarification was needed for the students to understand the ramifications of scoring included within the learning comic. Remarks such as, "I don't care about the score", "How many points do we get?" as well as a straight "No!" when asked about whether or not a progress bar would be helpful might be an indication of some mistrust in the way that some of the gamification elements were proposed to be included within the design.

One participant who was sure the features were part of some further "auditing" process linked the inclusion of these elements to assessment. Although more comments were indicating a fear of any measurement in the form of the learning comic, one participant opposed this view by saying "I think it would be good to...that pushes you faster to do better... When you're learning...it helps you, pushes you and tests your brain".

Overall both the addition of gamification elements and narrative design within the creation of the learning comic prompted positive, energetic and lively discussion.

6.3.7 Narrative design

The inclusion of a narrative within learning programming could steer the discipline along a more holistic path. Empathy and respect for the early pioneers of programming could bring the characters closer to adolescents and in turn the 'logic' of the discipline would follow. While narrative design within the education of computer programmers is usually un-addressed, in the focus group discussions the stories I recited of Alan Turing, Grace Hopper and John Von Neumann garnered attention from the participants. Inclusion of narrative in lessons can reveal processes of discovery and resilience as well as mathematics, logic, physics, mechanisation and computation. The character drawings on the first pages of the lessons that accompany this research are examples of narrative non-fiction elements. The narrative design within TOAOCP aided by the pictures successfully explained programming concepts to the participants.

6.3.8 Usefulness

As Usefulness had increased from the pretest to the posttest 6.1.4, I looked for evidence of Usefulness within the focus group discussions and coded the statements made by the participants. The Usefulness nodes indicated comments by the participants reflecting that they thought the learning comic would be useful in learning computer programming. The participants believed they would understand computer programming more because of the comic. Therefore the learning comic was useful from the perspective that the comic enhanced perceived understanding. In this study, Usefulness has been defined according to perceived usefulness (see Chapter 5, Section 4.5.3) as per Davis (1989) and is the degree to which a person believes that their job performance will be enhanced by using a particular piece of technology. In TOAOCP the devices of thought or technology are pictures and comics. Participants also believed the comic was easy to learn computer programming through. The comic was useful in that it was perceived by the participants to be easy to use. The qualitative findings reflected the Usefulness score of the comic in the Section 6.1.4 increase in the posttest. After using the comic to learn computer programming, the participants believed the comic to be much more useful than before they had used it. The quantitative measure of Usefulness significantly increased for the participants after they had used the comic to learn computer programming. Usefulness was a component of Attitudes that impacted upon the Intent to use a comic to learn computer programming (see Section 6.1.3).

Some participants suggested that they formed mental images when learning and suggested that the pictures were useful in helping form these mental visual images. One participant stated that in regards to learning from pictures, "You realise that you visualise what you would do", and another participant also added, "Cause like the picture helps me remember what it is and the words help me understand". The participants generally found the third type of vision (see Chapter 4, Section 4.2.2) worked within TOAOCP and that the pictures were valuable memory aids in learning.

The posters (see Chapter 5, Figure 5.24) were shown to the participants as artefacts to engage them and serve as narrative prompts for some of the concepts within the milestones. The participants also believed the posters would be useful for explain programming concepts within a lesson.

6.3.9 Fear of new learning experiences and fear of assessment

I coded Fear nodes in the analysis of the qualitative data from the focus group discussions. These codes reflect the participants' anxieties about learning through a comic, learning through a picture and also learning the context of computer programming. It was not always clear whether the participants had concerns about the way the learning was presented, that is the visual communication of pictures and comics, or whether the participants' concerns were about the learning of computer programming. The definition of fear was discussed in Chapter 5, Section 4.5.3. Therefore separate nodes were made in NVivo to reflect these three areas. The first Fear node, that is, Fear of assessment is now addressed.

Another area within the transcript that revealed Fear of assessment was associated with the scoring feature of gamification that could be incorporated within the learning comic. Scoring could be an enhancement included in a digital version of the comic. There was anxiety in both groups about how this feature would be administered or monitored. Scoring was not seen as offering any benefits to the participants but more as a didactic or teaching measure that would, to quote one participant "audit" the students. There was a need for control over how the data was used by the students. For example, they were happy to have the score data used as a method to achieve a badge or make an achievement however, they were not so positive about the score being used in a grading context.

There was also a general lack of confidence concerning interpretation of the pictures during the focus group discussion. Concern regarding pictures was generally connected to the participant's confidence in their ability to translate or understand the pictures. This was reflected in the quantitative findings on pictures (see Appendix C). The concern explains the decrease in the Usefulness items from the pre and posttest comparisons (see Appendix C). Although participants on average scored highly in the knowledge test (see Section 6.2.1), the knowledge transfer from the picture was of concern to the participants. The participants expressed that the picture's appearance was what they interpreted. Anything beyond the appearance was not considered by the participants. The aesthetic nature of pictures was referred to by one participant as what they were "so used to" which is in line with Papert's Principle discussed in the literature review, Section 4.3.8. Participants expressed that they were used to reading (text) for knowledge transfer as their priority had been linguistic learning.

The agency of graphic design within the learning materials was again referred to, with participants wanting words and pictures presented together. Added concerns from the participants included statements such as "...sometimes the pictures don't fill in the information that words could be able to" and "I find that it's easier to use words because say when you're answering something or explaining, you have to use words to explain it". The latter statement is also a reflection or response on assessment practice being mostly through linguistic feedback. Students are used to reading text to learn and also responding with text to be graded or assessed.

6.3.10 Intent

Participants responded enthusiastically to learning through a comic and confirmed that they expected to learn something about programming. As the context of computer programming was used, it is assumed that the feedback was contextualised to programming. The items concerning intent and programming were Question 12, items 2.16 to 2.18. The definition of intent within TOAOCP was first addressed in Section 6.3.10. The significant impacts of participant Attitudes towards pictures and comics upon Intent were quantified in Section 6.1.3 and Section 6.1.3. The participants' comments reflected the findings within the quantitative data. Intent to learn to program through comics increased from the data gathered in the pretest (t0) to the data gathered in the posttest (t2).

Agency or level of graphic design was again referred to, with the participants requiring clarification about the ratio of pictures to words. Here, the level of graphic design, or agency, employed within the artefact seemed synonymous with the amount of pictures within it, that is, it was easier to draw a picture concerning the information, than to describe the programming concepts with words. The following quote gives insight to the connection between agency and the intent to learn to program through a learning comic:

> I think the comic is quite cool but I think I'd probably like a little bit more words to explain it. But the comic, like the pictures to go with it is good. (Participant in Tarr, 2016)

This willingness to discuss agency also contributes to the participants' desire to co-create their own learning materials. Co-creation of learning materials is an area for future research along with prior knowledge and its contribution.

6.3.11 Prior knowledge

Introducing these students to a different-looking learning artefact from what they were used to, brought a fresh approach to conventional research paradigms and methods for both myself and the participants. The theme of prior knowledge also re-emerged during the qualitative phase of the research. Prior knowledge was defined in Chapter 4, Section 4.2.4 and is the knowledge a student brings when learning new content. What students were previously aware of within the disciplines of visual communication and computer programming was raised approximately ten times during the sessions.

Prior knowledge was divided into four different nodes for coding in NVivo. There was a node coded for general comments made about prior knowledge as well as nodes on prior knowledge of pictures and computer programming (aligning with the quantitative measure see Section 6.1.5).

In addition to these nodes, a specific node was coded for prior knowledge of comics as this was unmeasured in the quantitative analysis. This classification was necessary because there were different themes within each design element that were to be researched from the literature review. Prior knowledge itself has an impact on being in flow (see Section 6.1.5). Skill set is dependent upon prior knowledge and there was a relationship that emerged in the quantitative results on prior knowledge. The higher a person's skill set is within a particular area, the more in flow they will feel when performing that task. The hypothesis for prior knowledge was detailed in Section 5.2 as (H4p) on pictures. There was no reliance on previous programming knowledge for pictures to be seen as useful. As discussed within the literature review (see Section 4.2.1) the failure to establish this hypothesis (H4p) leans towards the existence of expectation failure. Students with prior knowledge about computer programming may not find pictures useful in the construction of new programming knowledge as these may conflict with their existing mental models.

In some cases students would like examples of how to understand the pictures and this was also found in a recent study (Caldwell, 2012). This description reminded me of the ISOTYPE style education materials that were produced by Otto Neurath in the 1930s and how their current relevance should not be understated.

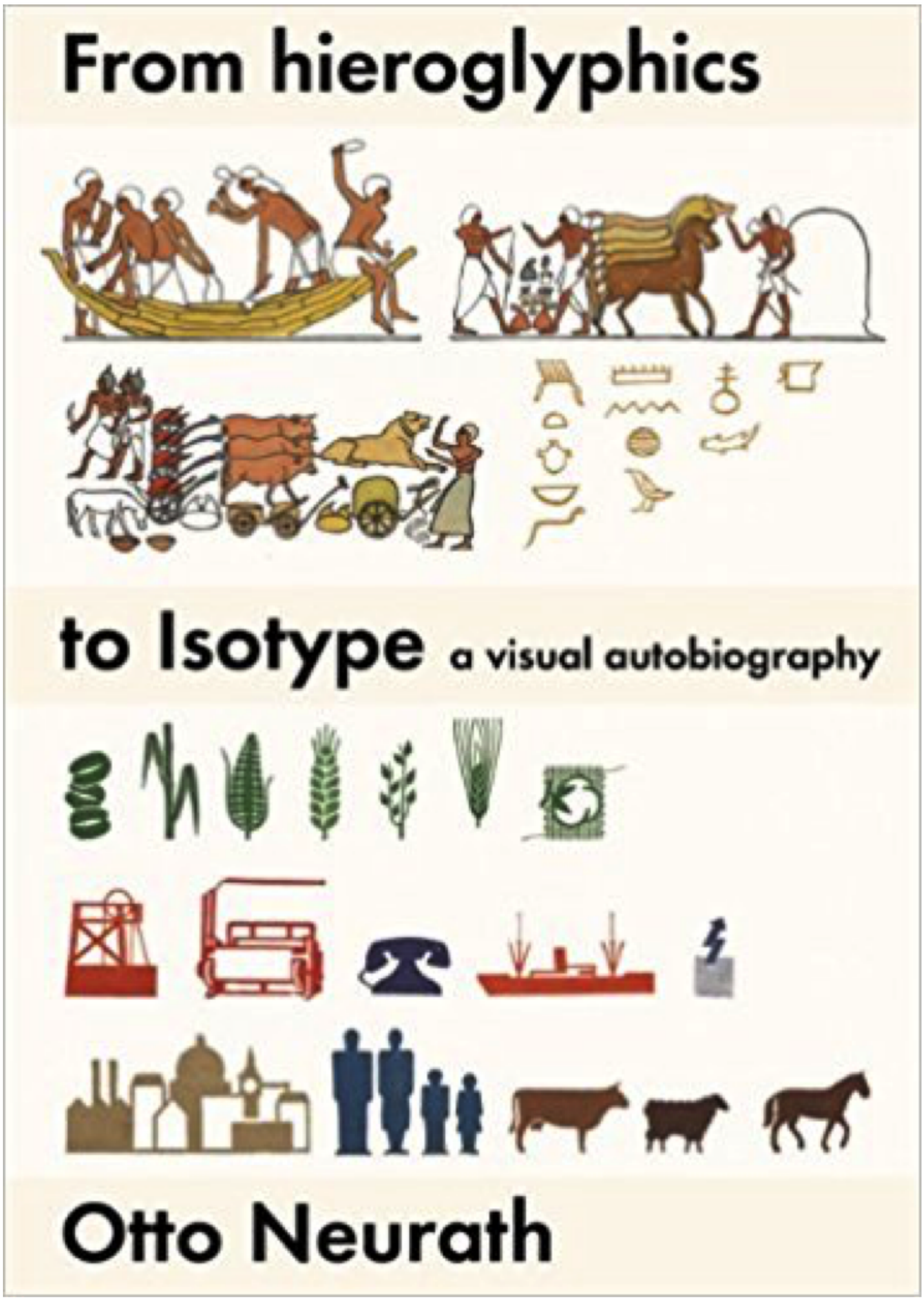


FIGURE 6.33: ISOTYPE education materials, Arntz (1930s), permission to use figure

Visual communication and computer programming were referred to as "hard to learn" by at least three participants. Students seemed to feel that the instrumentation presented was a "different way of thinking" and this was not disputed by other participants. This "different way of thinking" was not elaborated by the students within the time allotted. They were generally aware that they were accessing a different area of the brain from what they access normally. The reason the students gave for the information being difficult, was best explained by one student, "...because it is a different way of thinking". Whether this different way of thinking was directly connected to visual communication or programming requires further research. Other comments that support the presence of pictures in learning were " ... the comic, like the pictures to go with it is good" as mentioned earlier. The comments such as "I've got it ....OK" and "So it's like a sum" and "Oh Yeah" were referring to the fact that the knowledge transfer of programming occurred through the pictures. The students were understanding a programming concept that they had not understood previously that was binary tree traversal on pages 22, 24 and 26 of the instrumentation (see Appendix A).

6.3.12 Communication through pictures and words

Communication was assigned a theme or node within the research because of the need of the participants to discuss what role pictures play in memory and also what role the words play in understanding. Visual devices such as caricature (see Chapter 4, Section 4.3.4) and schema have been discussed (see Chapter 4, Section 4.3.2) as assisting memory when a person learns. Within TOAOCP schema and caricature were used in the visual communication. Communication was examined in the qualitative analysis (see Section 6.2.4) with regard to the role of pictures in learning. This theme could also be thought of as a sub-theme under the level of agency in graphic design and learning. Statements recorded within this node revealed some insight into what the students believed to be communication. Communication itself was seen as being directly connected to software such as Facebook. One participant in particular did not regard pictures as having any ability to represent a concept or to communicate at all, in other words, pictures were not regarded as communicative objects. This view was not contested by any of the participant's peers. I was asked, "Why would pictures be used in computers to communicate?" This statement revealed that the persuasive or convincing aspects of pictures are completely disregarded, and have as yet been undiscovered by some participants.

Closer inspection of the Wilcoxon Signed Rank test results for pictures in Section 6.1.4 revealed a decline in the measure of the Simplicity items after the instrumentation was used. Students believed pictures were easier to use before the use of the instrumentation that could mean they believed their visual literacy was higher than it was. After using the instrumentation, the students did not believe pictures were that simple after all. As far as analysis of any meaning beyond the representational, there was no evidence of this occurring. Pictures, to these participants, had no persuasive abilities. This lack of knowledge or deeper visual awareness has occurred despite the emphasis that the Australian National Curriculum places upon visual communication and the understanding of it both within high school and primary school (ACARAb, 2016; ACARAc, 2016).

Chapter 4, Section 4.2.5 has described visual literacy according to Debes. Visual literacy is knowledge that is not easily embedded into a curriculum, as individuals see images daily and are surrounded by them (Vermeersch & Vandenbroucke, 2015). Humans are born possessing 'built-in' mental abilities that stem from perception, which would indicate that the brain might not be a blank slate (Pinker, 2002). However, the ability to persuade with pictures is not considered within traditional education by the authors.

6.3.13 Fun and Enjoyment of pictures in learning programming

The two focus groups light heartedly discussed the content of some of the pictures. The tone within the focus group discussion at this time reflected the quantitative findings on Fun and Enjoyment (see Section 6.1.5 and Section 6.1.5). The pictures in the instrumentation were viewed as some sort of puzzle that there was an answer to. One participant was eager to understand what Seymour Papert was "looking at" and was also prepared to eagerly guess what Seymour was doing (see Figure 6.27).

Participants also asked detailed questions about elements in the documentation, particularly concerning pattern, with a participant asking, "Where's number three?" This question was in regard to the path of the binary tree on page eight of the focus group discussion questions and revealed engagement and curiosity from that participant to understand the picture further. There was a healthy interest in correcting the construction of the pictures as well as much as critiquing their meaning. A statement concerning the binary tree path, saying "make it less messy...", was a way for the participants and myself to consider improvements to the learning comic. Once the design of the instrumentation was seen as flexible and evolving, the participants actively contributed to different ways that the pictures and comic could be constructed.

The learning comic was considered as "cool", however, participants added that words were necessary for them to be able to clarify some meanings. The second focus group added that although learning through a comic would be fun, it would not necessarily be a natural process, reinforcing the early statements made about visual communication being a different way to learn. This was not only different for the participants, but completely new as they had not bee educated in programming through pictures before. When asked about how easy learning is with a comic it was agreed that "...it would be fun", but not necessarily easy. The participants during this particular focus group seemed unable to further elaborate upon why it would not be easy.

6.3.14 Video instruction

The participants discussed other ways to learn programming that were classified under the theme of Video Instruction. The discussion by the participants concerned methods they used to learn from video. Steps in the video were copied sequence by sequence and the video was stopped at each sequence while this occurred. Often steps were forgotten and it was necessary for participants to replay the video more than once. For example, a participant mentioned that videos were helpful for her, however she had to watch them many times and stop the videos a lot when learning. Participant control over the volume of information presented seemed to be a theme here.

Control over sequence of presentation of learning materials online has been found to have a significant positive impact on the learning of a participant (Brown, 2005). Within the focus group discussion sessions, discussion proceeded concerning the methods various students used to understand a programming concept taught with the instrumentation. Participants agreed that they would stop a video several times to understand the steps in learning a concept. Statements such as "Play it through... play it through then I get a question and I forget so I have to go up and stop it", "I play it through" and "I stop it" reflects the consensus that there was generally quite a bit of stopping and starting of the video when learning. The comments made by participants in this paragraph highlighted the difficulty the participants had managing the pace of viewing information when learning through images in motion. The participants expressed the need to control the motion of this information and to stop the information to allow learning to take place.

6.3.15 Comments supporting learning through line art

This section discusses the participants' understanding that the lesson delivered differed from how they had learnt programming before. The line art used within the instrumentation was a different component of a computer science curriculum that was addressed throughout this thesis (see Chapter 3 , Section 3.1, Chapter 4, Section 4.1.2, Section 4.2.2, Section 4.3.1).

Participants made a range of comments from "... so we understand more because of the pictures ..." and "I think explaining stuff with pictures is easier than explaining stuff with words ...". A participant in the second focus group (Brian) even went so far as to say the class had learnt better "Because there's pictures" (Tarr, 2016b). This participant was referring to the line art used in the instrumentation. Participants in the first focus group were clear that there were definite differences between the Mona Lisa (high realism) and a picture such as a map (lower realism) (Tarr, 2016a). The participants in this focus group concluded that different pictures had different functions and could also be used for different purposes.

As participants were new to describing the benefits of learning through pictures and comics, general words were used to describe the advantages; "But the comic, like the pictures to go with it is good". Generally, comments about the instrumentation (comic) were positive as the students said it was good and cool. When further questioned, participants began to reveal the advantages to learning in this way were “Because of the pictures” (Tarr, 2016b) which had been clarified as line art. Participants in both groups indicated there were advantages to using these types of pictures compared to how they usually learnt computer programming. Participants in the first focus group also described pictures as helping them to memorise information by saying "I'd rather have a clue book of pictures and a couple of headings, it makes me imagine more so what I think about is wholly and it goes in my brain a lot".

6.3.16 Results summary

Overall the findings from the focus group discussions were congruent with the data collected in the quantitative research. This congruency highlights the strength of a mixed methods research design. The learning comic was seen as useful to the students, and they might thus intend to learn computer programming in this way if offered the opportunity.

The impacts of learning computer programming through pictures and comics were mostly addressed under the impacts of meaning-making, cognitive load, aesthetics, learning visual communication, and Fear of comics and pictures. These areas formed the major themes of the qualitative research (see Section 6.3.1). Other minor themes that emerged from the focus group discussions which enhanced the qualitative results, were Co-design or Co-creation of learning artefacts, Gamification, Narrative design, Ease of use and Fun and Enjoyment.

The participants acknowledged that learning from comics would be fun and there was a general curiosity about the meanings of the pictures used in the instrumentation that could also be interpreted as fun. Participants of the first focus group required a lengthy discussion of how visual communication contributes to learning. Anxiety about implementing timing and scoring within a learning comic was expressed. These two gamification elements would need to be co-designed by the students and designer so as to guarantee participant acceptance. The need to contribute to the design of the learning comic was evidenced by numerous statements from the students.

The following figure visually summarises the different elements of design that are contained within TOAOCP (see Figure 6.34).

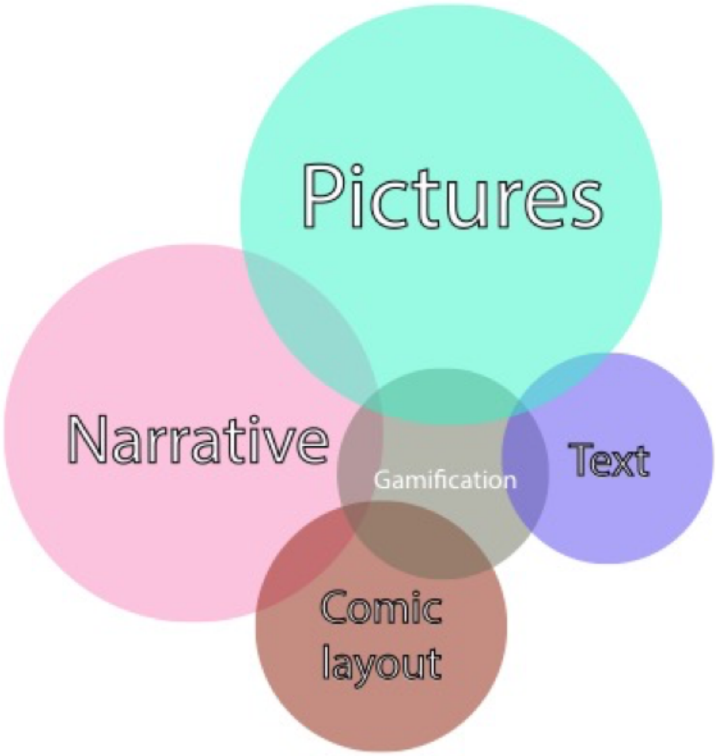


FIGURE 6.34: Design elements examined in TOAOCP

The size of the circles represents the level of agency for each design element within TOAOCP according to the participants. For example, the pictures were of most importance in the learning comic in comparison to the text that was there to explain the meaning of the pictures. Narrative design was also important in conveying meaning about programming to the students. This concludes the results section of the research.

Chapter 7

Findings and Discussion

Chapter 7 recapitulates the results starting with the pre and posttest comparison in the quantitative analysis. However, as the research now draws to a conclusion and the findings are about to be discussed, a summary of the thesis so far now takes place by chapter focussing on the specific topics that assist in explaining the findings.

Agreeing on what and how computer programming should work within a high school is challenging for teachers and adolescents (Chapter 1). There is a current focus into brain research by both medical and government agencies. Learning through visual communication is not a routine practice within high school education (Chapter 2). The research questions within TOAOCP explored impacts on cognition, motivation and the attitudes (values and beliefs) of adolescents when learning computer programming through visual communication (Chapter 3). Chapter 4 explored pictures, their sequences, and evidence of knowledge transfer when learning through these. There was a gap in the literature on learning to program through pictures, and approaches to learning complexity through visual communication in general. Chapter 4 also described how the initial instrumentation was based upon a technology acceptance model (TAM) and also described how the TAM was triangulated with the data that emerged from the focus group discussion sessions. Chapter 5 described the research design and methodology, while Chapter 6 described the results of mixed methods data collection through the participants' feedback.

7.1 Research Question One: Impacts upon the adolescents' perceived cognition

Three research questions were asked in Chapter 3 to examine the impacts upon learning computer programming through pictures and comics. The first research question examined the significant impacts of learning to program through pictures upon self-assessed cognition. These impacts were: usefulness; representation; self-assessed motivation; and flow (see Figure 7.1). Despite anticipating fun before using the instrumentation, the adolescents also found the pictures useful and that they contributed to being in flow. These significant impacts make sense because if an adolescent is not motivated to learn to program, their focus will be affected. Focus or length of concentration affects how well a topic is understood. Pictures which clearly derive from real object sources impact positively upon perceived cognition. If a picture does not have any representational value it is less likely to be understood. The highly significant relationship of Picture Representation to Self-Assessed Cognition in Figure 7.1 is the evidence for the significant understanding when learning programming through pictures.

The TAM impacts were measured to assess their influence upon self-assessed cognition to supply the answer for Research Question One. The impacts upon self-assessed cognition are now addressed individually starting with usefulness.

FIGURE 7.1: Quantitative impacts upon self-assessed cognition

7.1.1 Usefulness

Usefulness is viewed as one characteristic within a TAM that persuades the adoption of a technology. According to Tversky (2015), pictures are devices or tools of thought (see Section 4.2.4). TOAOCP uses pictures in the same way. The participants perceived pictures as useful devices for intent to learn computer programming. Pictures positively affected the participants' intent to learn programming (see Chapter 6, Section 6.1.9, Hp1) and self-assessed cognition (see Chapter 6, Section 6.2.3).

7.1.2 Picture representation

Picture representation within TOAOCP concerned how well the participants believed that the pictures explained new programming concepts. Picture representation also positively impacted the self-assessed cognition for the adolescents. How an individual perceives visual information impacts upon how well they understand a concept. Picture representation items measured how the participants viewed or considered the pictures within the artefact presented to them. In the process of recognising the pictures in the artefact, the participants were mapping the images stored within their minds to a single object representation. As discussed in Chapter 4, Section 4.3.2 as the participant's eye recognised something they had seen before, schema was reorganised to include the new or beheld information.

7.1.3 Self-assessed motivation

Self-assessed motivation (SAM) was another positive impact upon self-assessed cognition. SAM positively impacted the self-assessed cognition because when the participant's interest in programming was increased, they wanted to learn more and felt they were more aware of programming concepts. Participants also believed they understood the programming. According to Venkatesh (2000), intrinsic motivation is an anchor that determines an individual's ease of use of a new system. As a person's experience increases, the way they perceive the usefulness of an artefact or how easy the artefact is to use adjusts objectively. The participants' self-assessment of their intrinsic motivation increased with usefulness and their self-assessed cognition or understanding of the pictures.

7.1.4 Flow

Flow also had a positive impact on self-assessed cognition. Flow, according to Csikszentmihalyi's theory, is when a learner intensely focuses on activity (see Section 4.3.6). Within TOAOCP, as flow increased, the participants believed they understood the programming concepts better. The pictures within the comic positively impacted the participant's ability to be in flow when learning.

The impacts of usefulness, representation, self-assessed motivation and flow are the impacts upon self-assessed cognition which answers Research Question One. Namely: What are the impacts on cognition of using pictures in learning computer programming?

7.2 Research Question Two: Impacts upon the adolescent's perceived motivation

What follows is a summary of the findings for the second research question: What are the impacts on motivation of using pictures to learn computer programming? The impacts for this research question are also summarised in the Table 7.1. The significant impact on motivation when using pictures to learn programming was visual literacy (more specifically the factor picture literacy), that is, understanding the pictures (see Chapter 6, Table 6.9). Participants' personal ability also impacted the participants' motivation, however these were not as strong as picture literacy (see Figure 7.2). Picture literacy is focused on in the following section. A visual communication curriculum could be designed to influence the participants' motivation depending on how easy the pictures are to interpret by the learner. The more exposure a student has to visual communication examples and exemplars, the more confident they become in their ability to interpret a picture.

The impacts upon the motivation to learn computer programming through pictures are now addressed individually.

7.2.1 Picture representation and picture literacy

The picture representation and picture literacy factors were constructed from items that measure the understanding participants had concerning the pictures within the instrumentation of TAOCOP (see Appendix A). These items were included in the research to provide a more precise measure of how well the participants perceived that the picture designs communicated in the instrumentation. The two factors had similar items to be sure that they were indeed significant. The items that measured picture representation are:

> The pictures explained things (item 3.16);
>
> I felt confident I learnt something new with the pictures (item 3.17);
>
> The pictures revealed information to me (item 3.18).

The items that measured picture literacy repeated the first two items in the picture literacy measure. The items in picture representation were:

> The pictures explained things (item 3.13);
>
> I felt confident I learnt something new with the pictures (item 3.14);
>
> When looking at the pictures, I understood the concepts (item 3.15).

As both picture representation and picture literacy impacted motivation, pictures within TOAOCP were perceived by the participants to have an ability to convey programming concepts. Because the pictures explained programming concepts to the adolescents, their intrinsic motivation was impacted positively.

7.2.2 Personal ability

Maintaining a positive idea of self even when confronted with difficulty depends largely upon personal ability as well as some other internal factors (Agha, 2014). Personal ability has been found to be impactful upon work behaviour and learning in a variety of disciplines (Porter et al., 2003; Piasecka, 2011). The personal ability of participants was also a factor that impacted upon motivation positively. While the pictures increased the participants' personal ability marginally (that is, not significantly), the pictures in sequence (or the comic) increased the participants' personal ability of programming skills significantly (see Chapter 6, Table 6.5 and Figure 6.3).

7.2.3 Self-assessed cognition

The self-assessed cognition of the participants positively impacted upon their intrinsic motivation. The more they believed they understood the programming concepts through the pictures, the more motivated they were to learn computer programming through pictures.

Themes identified in the qualitative methods (see Chapter 6, Section 6.3) also reflected questions concerning the participants' ability to interpret a picture and beyond anything representational or what it looks like. The adolescents wanted to understand the pictures in order to learn programming. It would seem that understanding the pictures is a strong intrinsic motivator, according to the model in Figure 6.8. Picture understanding was a topic that also received energy and attention from the participants during the focus group sessions. This section concludes the summary for Research Question Two.

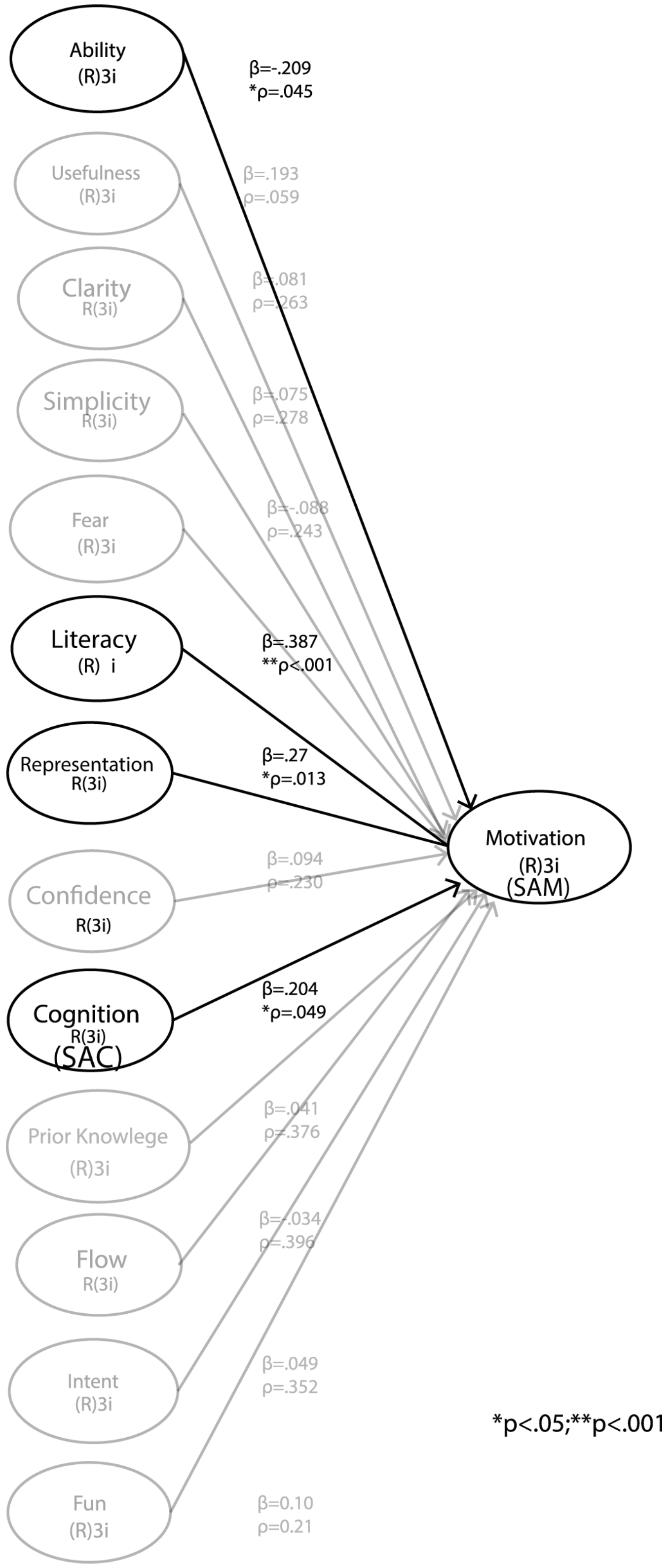


FIGURE 7.2: Quantitative impacts upon self-assessed motivation

7.3 Research Question Three: Participant beliefs and values toward learning computer programming though a visual artefact after the treatment

This section addressed the third research question: How are a Year 8 student's values and beliefs about computer programming impacted through using a visually designed lesson? A comparison between the participants' intent to learn programming and their attitudes that stem from beliefs and values (see Chapter 4, Section 4.5.1), showed a significant increases across all the participant groups when they used the pictures. A Kruskal-Wallis test demonstrated that intention to learn programming did not differ significantly between the sample groups (Section 6.1.3). A linear regression revealed that fun and enjoyment when learning to program through pictures was highly significant upon intent (see Section 6.1.5). Another positive relationship emerged between fun and motivation when learning to program through pictures (see Section 6.1.5). The participants thought the comic was useful, simple, and their personal ability or confidence to program increased after they used the learning comic. They were also less fearful of learning programming after using the comic. While the participants saw the comic as fun to learn programming with, other factors (usefulness, simplicity and personal ability) emerged that were more significant after using the treatment.

Technology acceptance models (TAMs) were designed to measure the attitudes of a person toward using a learning comic. The attitudes stem from an individual's beliefs and values about a system (as discussed in Section 4.5). The learning comic had a favourable impact on the participant's attitudes that have stemmed from their beliefs and values about computer programming. The qualitative data demonstrated positive impacts of the learning comic on the participant's beliefs and values. According to the participants, computer programming is difficult to learn. An artefact such as a learning comic may change this perception of difficulty. The impacts for Research Question Three are also listed in the Table 7.1.

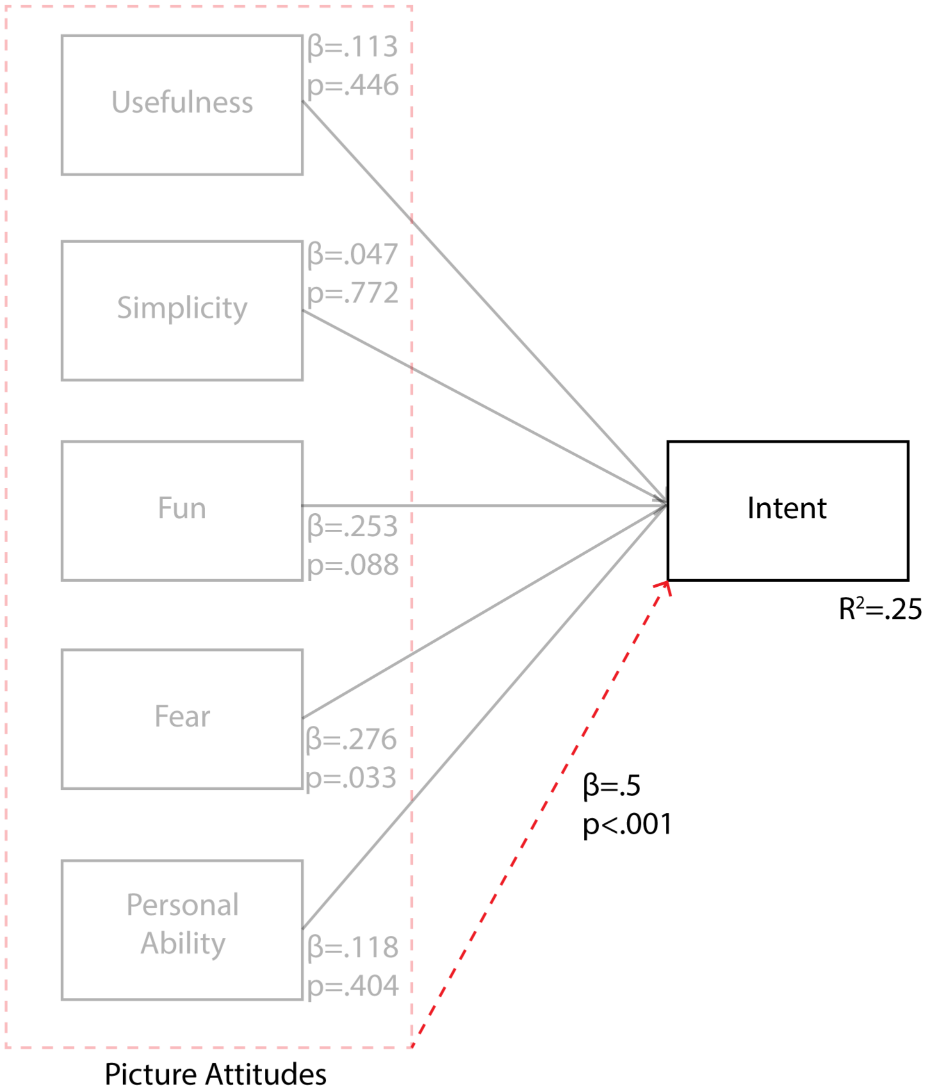


FIGURE 7.3: Attitude impacts upon intent, with regard to pictures

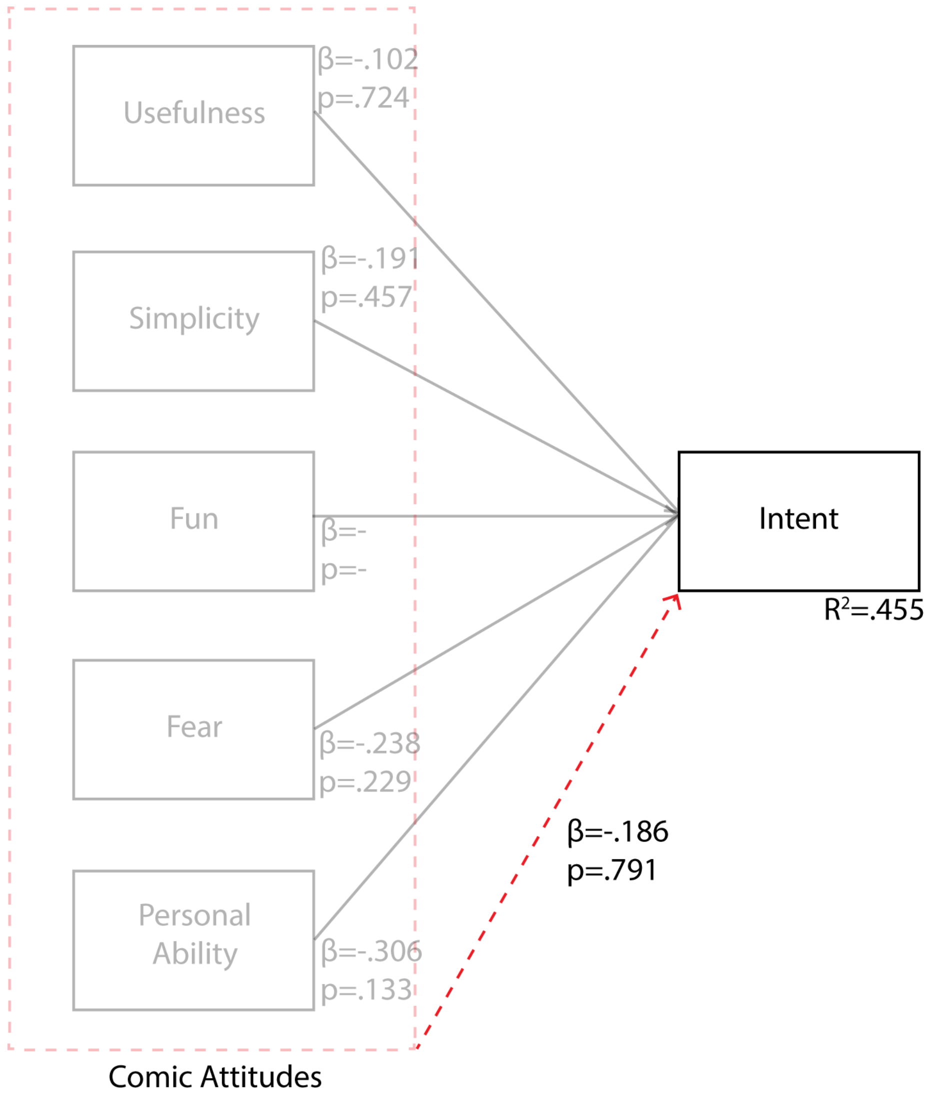


FIGURE 7.4: Attitude impacts upon intent, with regard to comics

TABLE 7.1: Summary of research questions and their answers

	Research question	Impacts	Method
1	What are the impacts of using pictures on cognition in learning computer programming?	Usefulness, representation, self-assessed motivation, flow	SEM
		Fun	Focus group session
		Rhetoric	Focus group session
2	What are the impacts of using pictures on motivation to learn computer programming?	Literacy, representation, self-assessed cognition, personal ability	SEM

continued . . .

	Research question	Impacts	Method
3	How does learning through a visually designed artefact have an impact on a Year 8 student's values and beliefs about computer programming?	The attitudes were impacted positively from using pictures to learn to program	SEM
		Fun and cognition	Linear regression
		Fun and motivation	Linear regression
		Subjective norm and cognition	Linear regression
		Narrative design	Focus group session
		Level of agency	Focus group session
		Gamification elements	Focus group session
		Intent to learn from pictures increases with usefulness	SEM Model for Pictures
		Fun with the pictures increases with usefulness	SEM Model for Pictures
		Fear has a negative impact upon the fun of learning with pictures	SEM Model for Pictures
		The more participants believe they understand programming with pictures, the more they rely on existing knowledge	SEM Model for Pictures
		Self-assessed motivation increases with self-assessed cognition	SEM Model for Pictures

continued . . .

Research question	Impacts	Method
	An individual's belief in their personal ability to learn programming increases the more they believe they understand the pictures	SEM Model for Pictures
	As intent to learn programming through a comic increases, so does the personal ability of an individual	SEM Model for Comics
	What friends and family think of learning programming through a comic increases with an individuals personal ability	SEM Model for Comics
	As understanding and strategy of reading from comics increases so does personal ability of programming	SEM Model for Comics
	Strategy impacts upon fear. As strategy increases fear decreases	SEM Model for Comics
	As the subjective norm increases so does strategy. The more supportive family and friends are about learning programming from a comic, the more strategy increases	SEM Model for Comics

continued ...

Research question	Impacts	Method
	The relationship between subjective norm and ability may be moderated by age. As an individual gets older, the opinions of friends and family concerning how they learn programming may be of less importance	SEM Model for Comics

7.4 Reflection on the quantitative approach within the methodology

The findings are addressed chronologically, that is, in the order that the data were collected from the participants. The next subsection summarises the findings from participant anticipations of learning computer programming through pictures.

7.4.1 How participants anticipated learning programming through pictures and comics: before the intervention (t0)

Participant anticipation was measured through the pretest (t0). Attitudes were the aggregate measure of usefulness, simplicity, fun and enjoyment, personal ability and fear. The participants' attitudes for both pictures and comics were overall positive before the treatment (that is, the learning comic) was issued.

7.4.2 Pictures after the intervention (t2)

Before the intervention the participants anticipated that pictures were useful, simple and fun to learn programming through. However after the treatment, participants found the individual pictures used within the instrumentation not significantly more simple, useful and fun than before the treatment. Although they believed the pictures in sequence to be beneficial to learn programming (see Section 6.1.4), participants did not think the individual pictures in the instrumentation were significantly useful and simple on their own. This finding could be because of the level of visual literacy of the participants, or more specifically, their ability to interpret pictures. In short, the participants were not comfortable with or used to picture communication and the fact that pictures can be designed to contain information essential to learning.

7.4.3 Comics after the intervention (t2)

Comics were also anticipated to be fun (see Table 6.6), however different priorities were given to the impacts of fun, usefulness and simplicity when they emerged in the posttest (t2). Although fun was still influential after the posttest when measured in isolation, the items for fun seemed to measure the same underlying construct between fun, usefulness and simplicity in the comic measures. After the intervention (t2), attitudes and perceived behavioural control were again positively related to the intention to learn computer programming through a comic, and the comic was valued higher for its usefulness and simplicity than for its fun or novel aspect. The comic was believed to be more useful, simple and increased the personal programming ability of the participants after use.

7.4.4 Increase in attitudes for pictures and comics after intervention (t2)

Participant attitudes after the intervention exhibited significant positive influence on intent for both pictures and comics. In short, participant attitudes toward learning through pictures and comics after using the instrumentation, positively impacted their intent to learn computer programming.

The perceived behavioural control also exhibited a significant positive impact upon intent for both pictures and comics. After using the instrumentation, participants perceived they had strong ability to learn computer programming through a comic. As perceived behaviour is an accurate reflection of actual behaviour, when given a choice to learn programming, the participants would choose to use a comic similar to the instrumentation.

The subjective norm, or what friends and family think of using a comic to learn programming, impacted how well the participants believed they would understand the comic. Age was moderated by the subjective norm when learning computer programming through a comic, in summary, what friends and family think had less impact the older the student was.

Gender did influence the intent to learn to program through comics, with males having a higher mean ranked data than females. Males wanted to learn programming through a comic more than females. This finding supports research on males generally wanting to use comics more than females, as well as males being generally more suited to comics (Merisuo-Storm, 2006; Sommers, 2000; Allyn, 2011).

7.4.5 Knowledge transfer or learning through pictures

TOAOCP found that knowledge transfer of computer programming through pictures was effective to two thirds of the adolescents in the study (see Chapter 6, Section 6.2.1). All picture hypotheses were established (see Section 6.1.9) while all comic hypotheses were established except one (see Section 6.1.9).

The behavioural affects of using design have been widely documented (Desmet & Hekkert, 2002; Fogg, 2003; Norman, n.d.). The literature on these affects extends across disciplines from health to education and also across the arts. Design researchers have given the emotional and social affects of design much attention; however, the area of learning that includes pictures, knowledge transfer though pictures and visual rhetoric has relatively little literature.

Except for a few noted authors (see Section 4.2.3), pictures are used by technical authors in programming as a decorative 'add-on' to existing text. Computer science diagrams are not necessarily useful in explaining how software works to novice programmers. The traditional method of producing computing curricula is mostly concerned with typographic issues and general layout. The milestones (see Appendix A) explored ways to represent the complexities of computer programming with pictures.

TOAOCP used two types of design elements and measured the intent of the adolescents to learn computer programming through each. Pictures and comics were the design elements measured that resulted in models on the intent to learn to program. Two models for intent were produced (see Figures 6.11 and 6.12) and developed through the use of a modified technology acceptance model (TAM) that stems from the theory of planned behaviour (TPB).

Data were collected during Research Phase Two (see Chapter 5, Section 5.3, Table 5.2) to classify the participants into a continua of skill sets to see how the study fared for those participants who rated themselves as lower skilled than their advanced peers. What the data revealed from the use of the pictures, was that the adolescents that assessed themselves as having a low programming skill set achieved the highest test scores (see Chapter 6, Section 6.2.1). The reverse was also the case as the advanced programmers scored the lowest test scores.

The rate of knowledge transfer for learners though visual communication is another area for further research. The actual test scores of participants was approximately 70% (see Chapter 6, Section 6.2) after using the comic to learn programming. By showing students their high test scores, they will be more likely to believe they understand a topic and their beliefs and values would be impacted. They would believe they were good at programming, particularly if they had not experienced much success in learning programming before using the instrumentation. Research Question Three was answered using data concerning the beliefs and values of learners and is discussed later within this chapter, see Section 7.3.

The graphic design (that is, visual realism, comics and the arrangements or layouts of the pictures) used in this study would appear to have reversed the participants' idea that those children who believed they did not have a robust skill set when it came to programming, actually did when learning through pictures and comics. Due to time constraints upon the teachers and in-class time restrictions, the opportunity was not available to pass the grades back to all the participants. A further research method would be to re-measure the participants' attitudes to learning through pictures after returning the test scores. The impact on the participants' beliefs and values from knowing their test scores could also be measured to ascertain a change.

My research, that concerns predicting an adolescent's intent to use a comic to learn computer programming because of the pictures within it, is not a common area of research. Although the knowledge transfer returned a satisfactory to good result from the instrumentation (see Chapter 6, 6.2), participants were unsure of the picture meanings (unless they were in a comic) and were not used to speaking about pictures and how they communicate.

7.5 General themes arising within the study

I made observations while conducting this research that I feel should be included for both the future direction of TOAOCP and also because there were incidents that caught my attention. As the class time with the participants was limited for conducting TOAOCP, the following themes have been detailed for other researchers wishing to carry on this research. Therefore in addition to themes that arose from the research questions classified by the NVIVO nodes, themes arose from the literature review, data collection and focus group discussions that could be used to generate a framework for making pictures that represent programming. The themes of TOAOCP align with some principles of Universal Design and Learning:

- The students should have opportunity to construct their own learning artefacts. These artefacts should take the form the student desires;
- The students should have knowledge of constructing pictures, understand visual communication and also have the capacity to share and critique these pictures;
- All students should have an appreciation of programming and its applications;
- All students should understand ways to organise prototype construction along with sharing and critiquing these prototypes.

Learning has changed due to the amount of information readily accessible to students via the Internet. Recent claims within a PhD upon how interaction affects information acquisition are: "With the maturity of the Internet in the past decade, online interactivity has extended both the dimension and the meaning of information acquisition" (Yan, 2008, p 53) and "Compared to the original face-to-face instruction, online instruction creates a new environment that makes the individual apply a multi-dimensional learning approach" (Yan, 2008, p 54). These claims by instructional designer, Dr Wu Yang concerning a transition from traditional to that of digital education are echoed through publications from academics focused upon online learning (Bawa, 2016; Sontag, 2009; Saadatmand & Kumpulainen, 2012). As students now have access to endless amounts of information, problems have presented that work against learning (see Section 4.3.8). Pictures have a part to play in lessening overload from abundance of information (see Chapter 6, Section 6.3.3 and Section 4.3.8).

The additional themes mentioned above would help any future high school projects that focus on ways of using visual communication. Future projects that come from TOAOCP would focus upon the creation of pictures as devices that transfer knowledge. Teachers are now looking to the discipline of design for tools to improve education systems (*Design thinking for educators*, 2018). Companies such as IDEO promote *Design Thinking for Educators* and *Design Thinking for Libraries* as toolkits to optimise organisations (IDEO, n.d.-a, n.d.-b).

7.5.1 The role of pictures in learning computer programming

The findings and discussion section now focuses upon the last set of data in the results, that was, the role of pictures in learning computer programming. With the data collected at the high school level, most participants thought pictures held predominantly aesthetic or communicative abilities. Meaning-making according to the participants, was not a predominant reason of why pictures were used in the computer programming education context. The finding concerning appearance, supports Papert's principle, discussed in Section 4.3.8. During the focus group discussions, participants described computer programming as difficult to learn. Here participants were describing that their understanding or mental models were conflicted. Papert's principle states when communication systems conflict, society resorts to appearance (what can be quickly interpreted by sight), in other words, what things look like. However, the dominance of aesthetics was not consistent with the data collection in the primary school. It may be the case that the majority of students completely change their view of the role of pictures in learning when they graduate to high school. The role of pictures in learning changed from primary to high school in TOAOCP. The primary school participants valued pictures in learning computer programming more for their meaning-making role.

TOAOCP used line art pictures to communicate. These pictures either resembled something in the real world, or they were abstract and diagrammatic. The abstract and diagrammatic are often arranged in a layout or order to help schematic processes within the brain for the beholder of the information (see Chapter 4, Section 4.3.3). Within learning, perception interprets sensation, and different types of pictures can be designed for an individual to achieve this learning. Different types of pictures from realistic to abstract can be classified according to the realism continuum (Chapter 4, Section 4.2.2). The brain prefers the less realistic pictures when processing meaning. When learning or transferring knowledge, these less realistic pictures have less noise. (Medley, 2013b; Carstens, 2004). Diagrammatic pictures assist organisational processes used for sense-making in the brain, all of which is essential to learning computer programming.

7.6 Summary of the findings

The summary of Chapter 7 occurs chronologically according to the order of the data collection where anticipations of the participants were measured (t0), the cognitive test was scored (t1), and lastly, the posttest (t2) and evaluation measures (t3) were addressed.

7.6.1 Anticipations toward learning through pictures (t0):

- Results of the pretest (t0) show that participants were positive towards pictures for the learning of computer programming. Fun was an incentive for learning programming through pictures for the participants (see Section 6.1.3).

7.6.2 Thoughts after using the pictures to learn programming (t2):

- After the treatment, the participants' attitudes were found to be significant upon the intent to learn computer programming; additionally, fun was the salient predictor of intent (see Section 6.1.3).
- The participants' attitudes toward learning programming through a comic were also positive (t0) (see Section 6.1.3).
- The participants believed the comic was useful, simple and their personal ability of programming significantly increased after the treatment (see Section 6.1.3).
- The fun and enjoyment experienced by the participants from viewing the pictures had a significant impact on their cognitive learning gain (see Section 6.1.5).
- As the participants' experience of fun when learning programming through the pictures increased, so did their motivation to learn computer programming (see Section 6.1.5).
- Being in flow had a strong affect upon the perceived cognition of the participants (see Section 6.1.5).
- What friends and family thought about the participants learning programming through a comic had a highly significant effect upon whether the participants believed they would understand the comic (see Section 6.1.5).

- Motivation and picture representation were the impacts upon the participants' cognition to learn computer programming through pictures. Other impacts upon the participants' cognition were usefulness and understanding.
- Picture literacy, personal ability, picture representation and cognition were the impacts upon the participants' motivation to learn computer programming through pictures (see Table 6.17).
- Several hypotheses were established for learning computer programming through pictures (see Section 6.1.9).
- Five out of six hypotheses were established for learning computer programming through comics (see Section 6.1.9).

7.6.3 Results of the knowledge test (t1):

- The participants rating their skill sets as "slight computer knowledge" on the instrumentation scored the highest in the test (see Section 6.1.6).
- Six questions were asked about programming in various high-level languages. The question concerning binary tree traversal was the most difficult for the participants to understand (see Section 6.2.3).

7.6.4 Gender and age:

- Gender and age influence intent to learn computer programming through a comic (see Section 6.1.9 and Section 6.1.9).

7.6.5 Models for intent to learn programming through pictures and comics:

- A student's intent to learn computer programming was significantly impacted through using pictures and comics. From the data collection process, I constructed structural equation models (SEMs). These models were constructed from significant relationships to predict the intent to use both pictures and comics when learning computer programming (see Figures: 6.1.9 and 6.1.9).

7.6.6 The role of pictures in learning computer programming:

- Aesthetics was more likely to be attributed to the role of pictures in learning as participants enter high school. In primary school, participants were more likely to attribute meaning-making to the role of pictures in learning (see Section 6.2.4).

7.6.7 Focus group findings:

- Participants feared being assessed when learning through pictures. Increasing the students' visual literacy could have a beneficial effect upon the fear of being assessed (see Section 6.3.9).
- The qualitative analysis showed that participants believed the learning comic to be useful to learn computer programming through (see Section 6.3.8).
- Participants viewed the narrative design of the computer programming instrumentation to be of high value to their learning (see Section 6.3.7).

7.6.8 Discussion on patterns emerging through the drawing process:

Throughout the history of computer programming patterns exist within the code that have been repeated. As TOAOCP took advantage of using pictures to represent abstraction within computer programming, documentation was reduced and pictures were reused throughout. I created a set of pictures to communicate the working of the Turing machine. Throughout creation of the milestones, I found that I reused these pictures throughout. For example, the same dotted wavy line used to indicate a basic algebraic subroutine of the Turing machine was used to explain a subroutine in an iPhone (see Figure 7.5 and Figure 7.6).

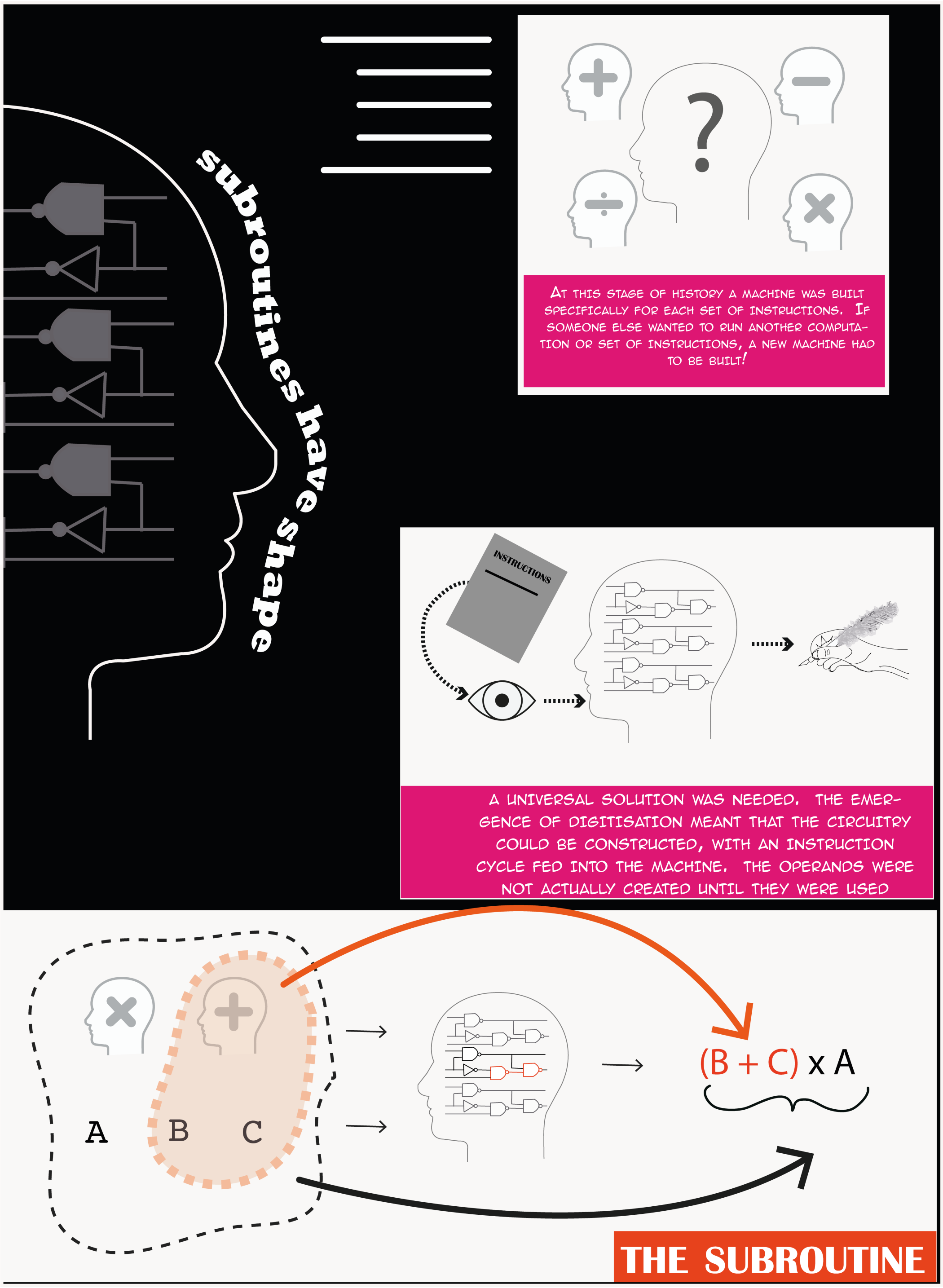


FIGURE 7.5: Subroutine illustration for Turing machine

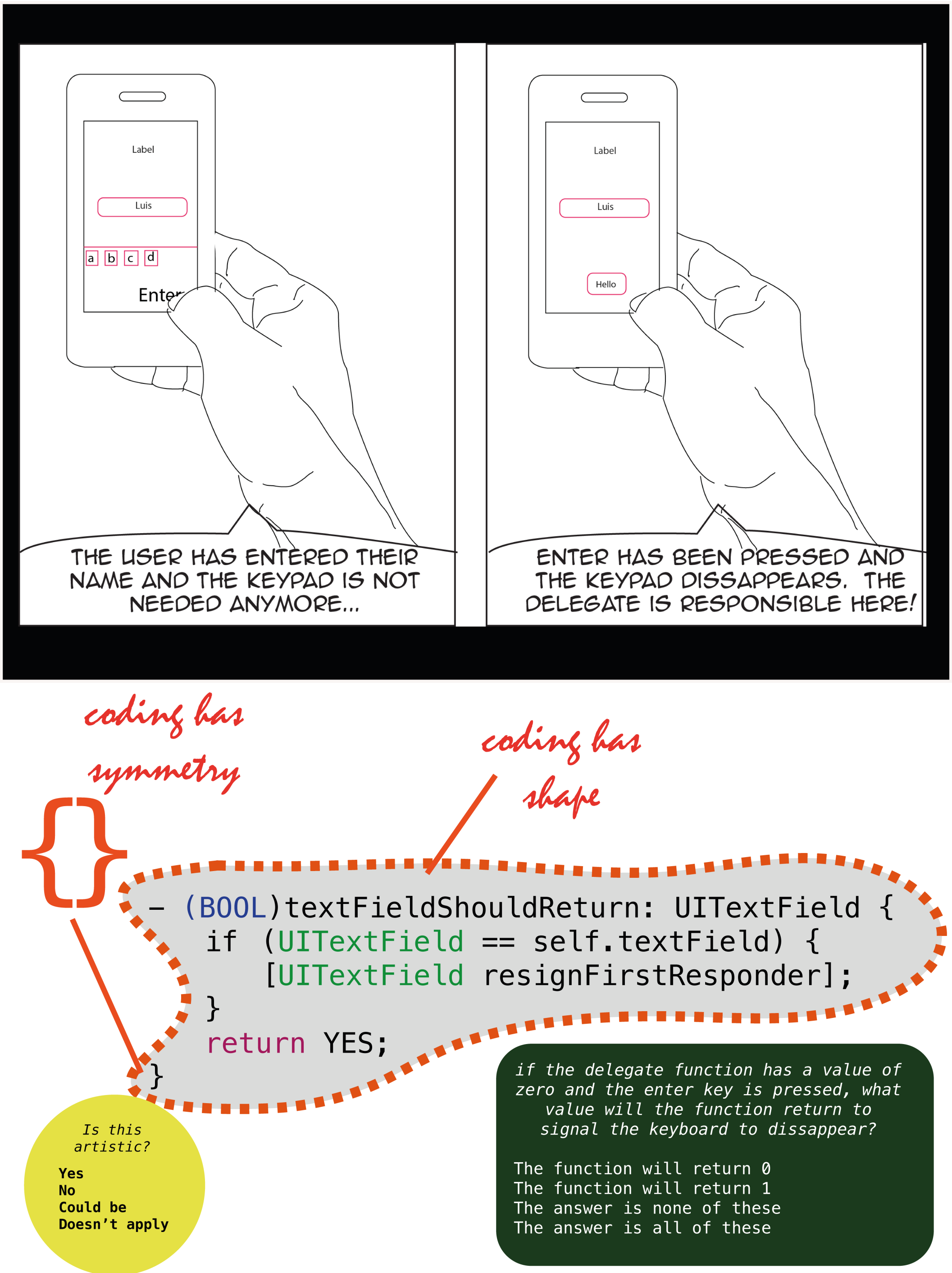


FIGURE 7.6: iPhone subroutine

Another example of reusing pictures throughout the creation of the milestones was by describing when locations are used in memory by software. Below are three examples from the first (Figure 7.7), forth (Figure 7.8) and sixth milestones (Figure 7.9) on the use of memory location when programming. Computer science has used some visual representations to communicate learning (Telea, 2014; Caserta & Zendra, 2010) and in the following section I reviewed some of the major examples.

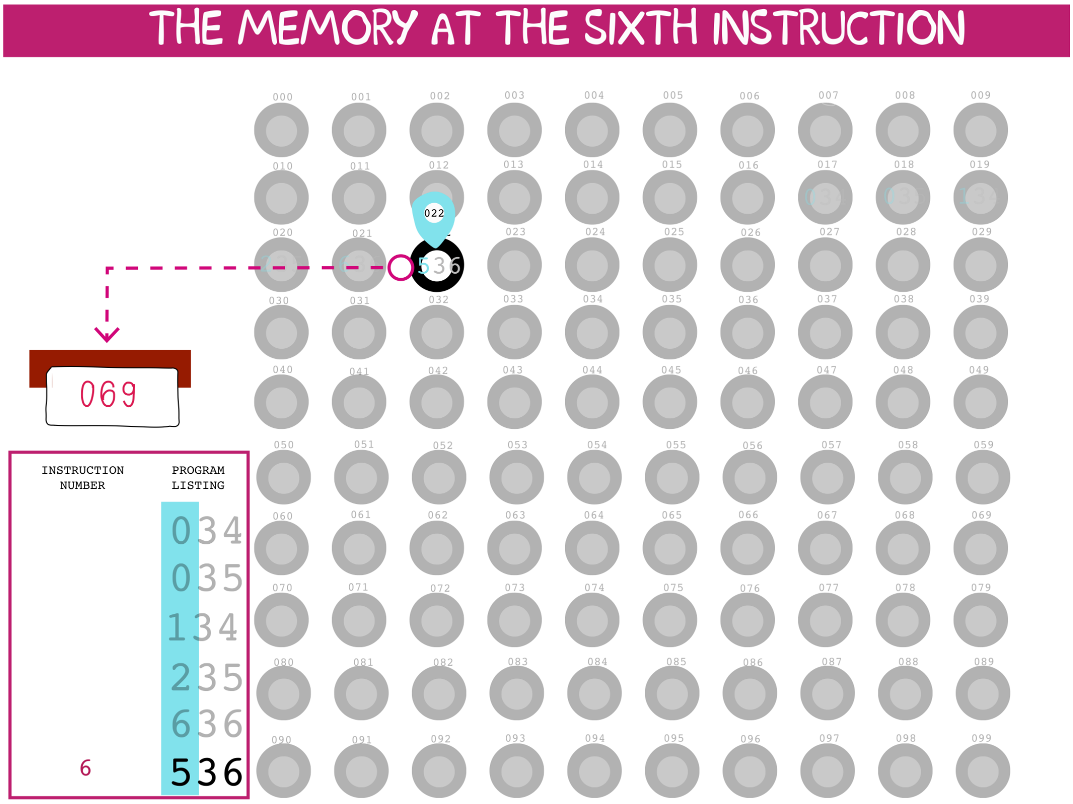


FIGURE 7.7: Memory allocation assembly code, milestone one

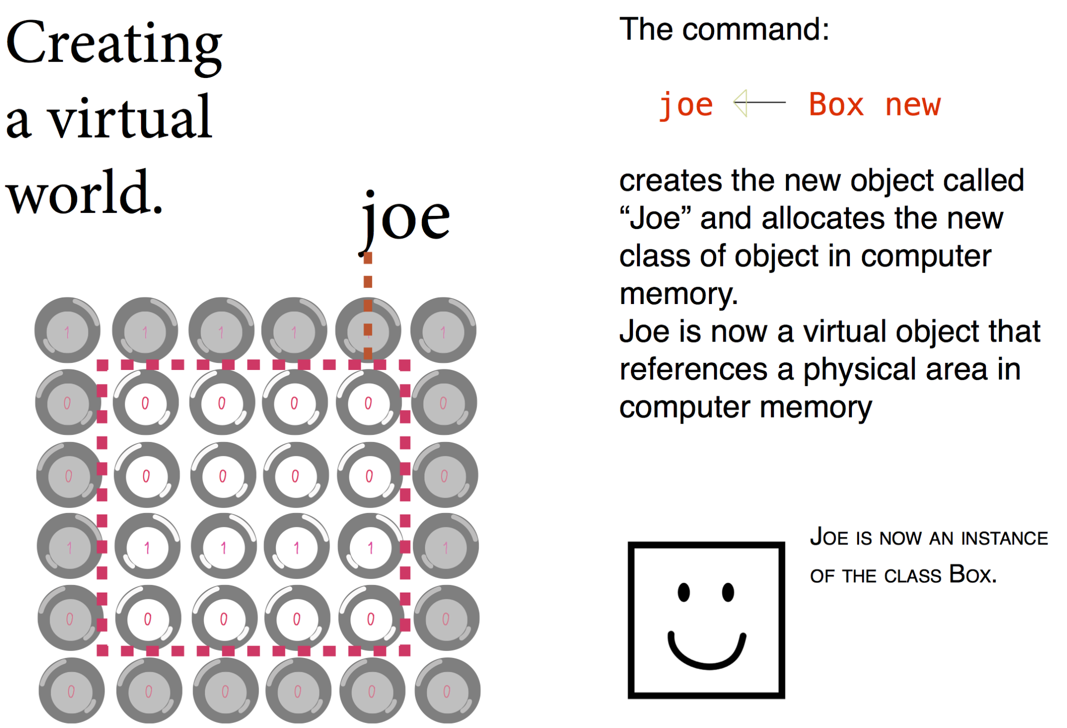


FIGURE 7.8: Memory allocation Smalltalk code, milestone four

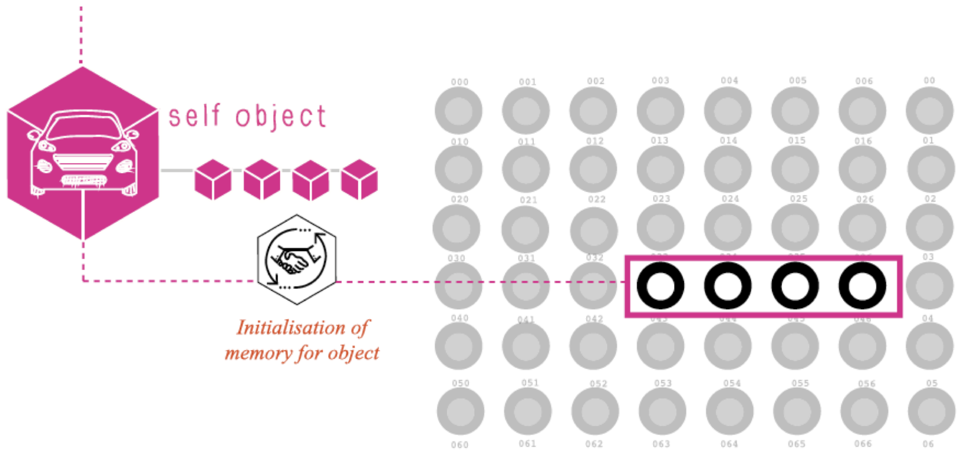


FIGURE 7.9: Memory allocation in object orientated programming, milestone six

Table 7.2 represents a summary of the repeated patterns and pictures used throughout TOAOCP. These pictures represent the vertical curriculum within TOAOCP and are concepts referred to throughout. A list or array of memory cells in milestone one is indicated by the same picture that is used in milestone six. This picture is three dimensional cubes in sequence connected by a line (see Figure 7.10 and Figure 7.11). Figure 7.12 shows the current lesson of milestone six while making reference to the product development lifecycle and model view controller (MVC) design pattern. Any pictures were reused in TOAOCP that could be. The last set of pictures I needed to create were for the product development lifecycle (see Figure 7.13). In order to firmly establish why TOAOCP is unique I have reviewed two other types of computer science documentation that utilise images and pictures in the following section (see Section 4.4.2).

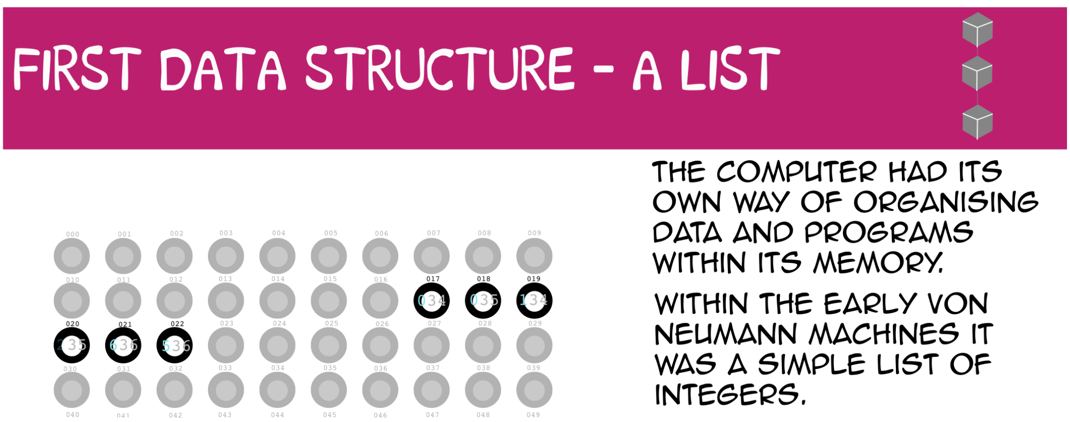


FIGURE 7.10: Array picture used for list in milestone one

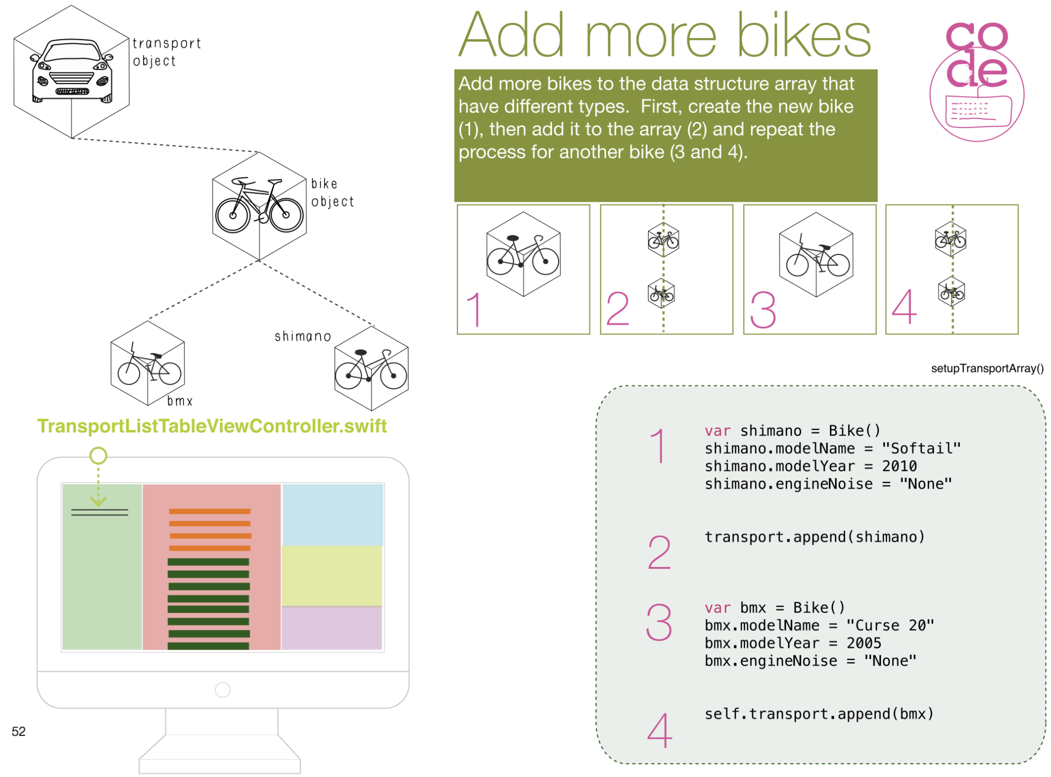


FIGURE 7.11: Array picture used for list in milestone six

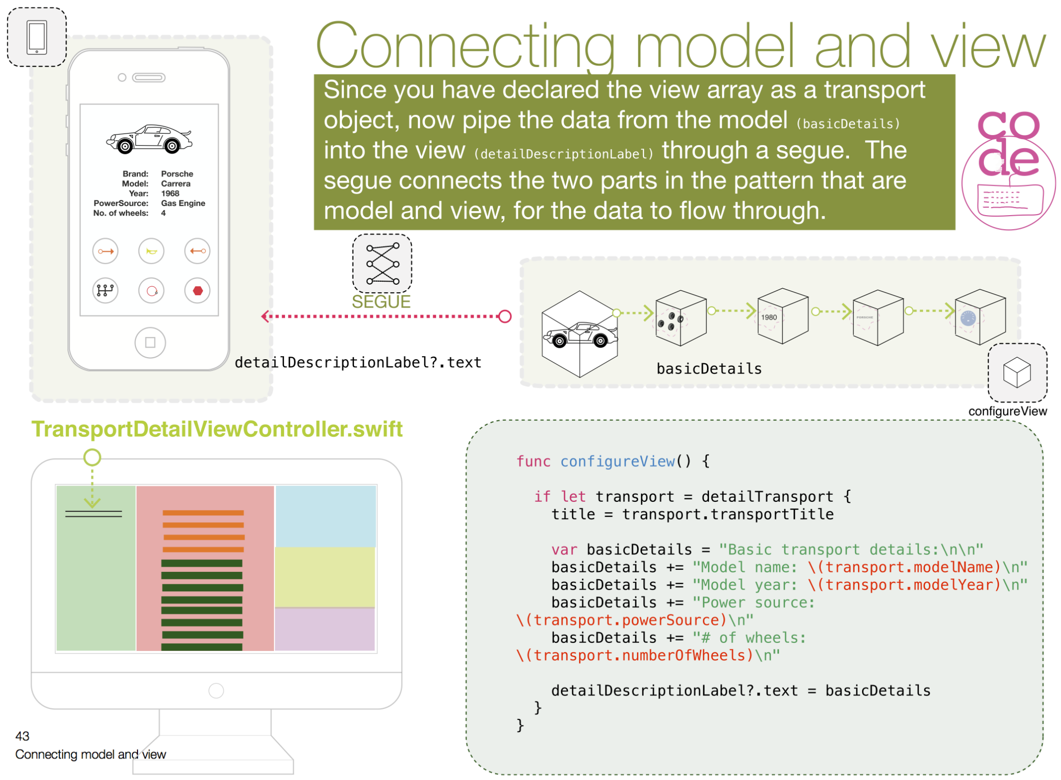


FIGURE 7.12: Example of model view controller - MVC design pattern and product development life cycle pictograms within milestone

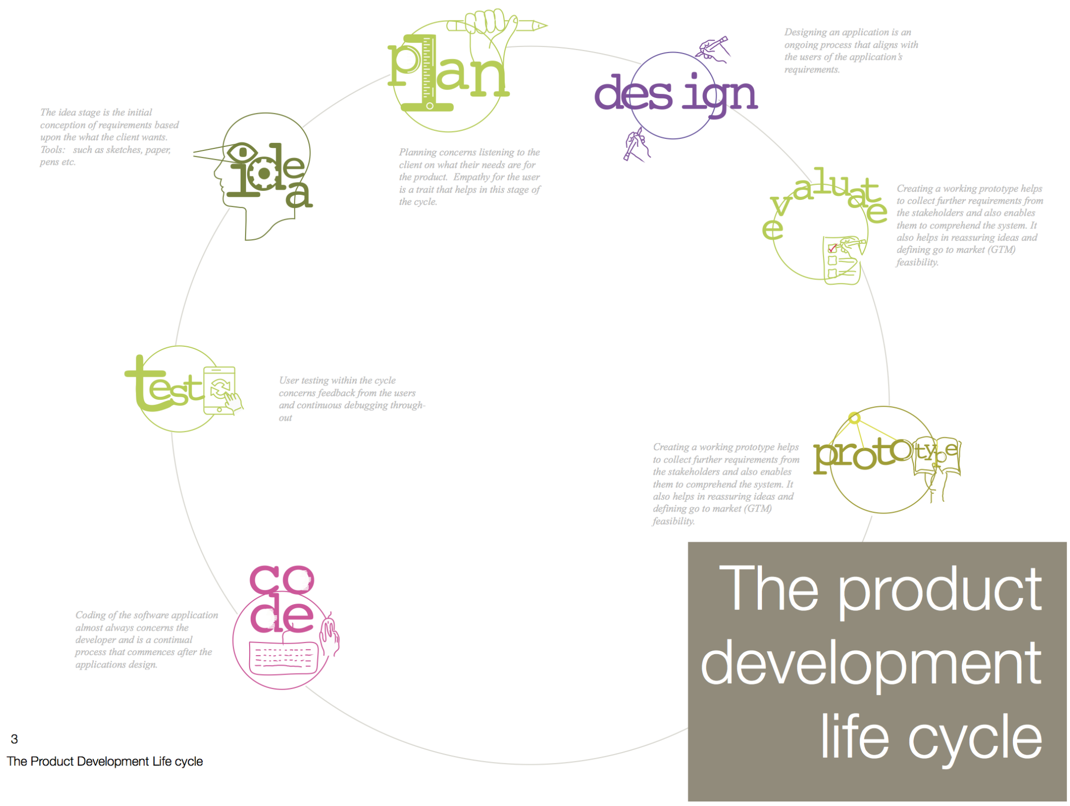


FIGURE 7.13: The product development lifecycle created for milestone six

TABLE 7.2: Repeating pictures and patterns in TOAOCP

element	**Milestone one**	**Milestone two**	**Milestone three**	**Milestone four**	**Milestone five**	**Milestone six**
memory cells	x					x
subroutine pictogram	x	x	x		x	x
Moore's law	x				x	x
data types						x
data structures	x		x			x
computational thinking	x	x	x	x	x	x
sequence, selection and iteration	x		x			x
design patterns			x		x	x
product development lifecycle						x

Chapter 8

Limitations of TOAOCP and Future Work

My research serves as an example of visual curriculum design focusing on picture interpretation as a sensory first response by students who are intending to learn programming. Within TOAOCP, the sensory response is the students applying vision to the pictures they encounter when learning. Analytical tools were created based on statistical data, and processes were borrowed from other disciplines to form the hybrid mixed methods methodology. The discussion that follows addresses limitations common to both methods within the study, followed by a breakdown into quantitative and qualitative limitations.

8.1 Limitations common to both quantitative and qualitative methods

8.1.1 Class time was limited

Initially more than one instrumentation for the participants was proposed. A series of lessons where the participants discussed the pictures used in the lessons and co-created their own learning materials would have been a better way to create the milestones. However, within the school system, class time is extremely limited and difficult to acquire. Instead, in order to secure the eight school groups, it was necessary to develop an instrumentation that would measure attitudes and evaluate the lesson in the one sitting. As a result, TOAOCP moved to a preliminary study. Although the participant numbers were enough to satisfy the valid structural equation modelling (SEM) analysis (see Chapter 6, Section 6.1). Had more time been available, I would have made a more extended analysis of visual communication using the methods detailed in Chapter 5. I would have co-created the milestones with the students. The limitation of the two 40-minute focus group discussions also meant that some of the topics could not be discussed in depth within the time allotted.

8.1.2 Limitations of the quantitative methods

Increasing the data collection impacts
This study introduced the concept of learning programming through visual communication within an adolescent environment. It used attitudinal factors derived from the theory of reasoned action (TRA) to measure impacts upon intent to learn programming. The concept of teaching through visual communication, namely through pictures and sequences of pictures, is different to the traditional methods of teaching computer programming. While the findings provide a general increase in intent to learn programming when the delivery through visual communication is applied, future studies could further examine the impacts of visual communication upon a range of other factors discussed later in this chapter in Section 8.2.3. The fact that behaviour and information anxiety was not measured is a limitation of TOAOCP.

The data does not explain the reasons why the impacts occurred, only that they occurred
Further triangulation of the quantitative data with the focus group discussions was necessary to explain the reasons why the impacts occurred. Data does not reveal the reasons why something happened only that the phenomena occurred. This disadvantage of interpreting past data is another limitation of the quantitative analysis.

The participant demographic sample was confined to the Perth metropolitan area
Adolescents in country areas did not participate within TOAOCP. Data from specific vulnerable groups as well as rural disadvantaged groups were not sampled. These results may not represent a comprehensive view of the Western Australian adolescent population. Mathematics and statistics are used to calculate quantitative analysis and generalisation is assumed in the results obtained (Martin & Bridgmon, 2012).

Along with the quantitative methods, there were also some limitations with the qualitative analysis.

8.1.3 Limitations of the qualitative methods

The participants' invention of answers during focus group sessions
Ideally participant focus groups are thoughtful, rational and intellectualised however not all human behaviour is rational. Much of human behaviour is not thought out as it is unthinking and unconscious. According to Zaltman (2003) 95% of consumer decision-making, particularly where behaviour is concerned, is unconscious. For this reason, focus groups can give results that are actually erroneous. This issue of results that are not correct is minimised where there is more than one line of enquiry to the research, as there was in TOAOCP due to the mixed methods analysis. Focus groups do not often reveal the emotions of the participants. Participants may also be unaware of what drives their behaviour and may be driven by emotions. They may invent answers to the questions.

Trivial comments during sessions
As the content within the instrumentation of TOAOCP was complex and the focus groups were large, that is, over 12 participants, and the time was restricted to 40-minute sessions each, there were superficial and trivial comments. For example, "it's tricky" or "it's cool" were vague and difficult comments to categorise. A smaller number of participants within the focus groups may have circumvented the triviality.

8.2 Future work: Raising the profile of picture communication

New forms of sense-making, to enable people to seek meaning and clarity in a visually saturated environment, are a future trend for graphic designers according to the American Institute of Graphic Arts (AIGA) (AIGA, 2017). A lack of certainty in interpreting the meaning of some of the pictures used in TOAOCP was a theme raised by some participants within the qualitative methods of the study (see Chapter 6, Section 6.3.12).

According to the AIGA designers' community, there are seven key trends that designers should be aware of to carry their skill set away from industrialisation and toward a knowledge economy. These trends are outlined in the article *AIGA DESIGNER 2025: WHY DESIGN EDUCATION SHOULD PAY ATTENTION TO TRENDS* and include: complexity; aggregation and curation; bridging physical and digital experiences; resilient organisations; core values; new forms of sense-making; and accountability for predicting outcomes of design action. The scope of my research deals specifically with the first point in the preceding section, that is, new forms of sense-making. Within TOAOCP the new form of sense-making considered was the picture. Picture metaphors (Seitz, 2005; Lakoff & Johnson, 2008) should they be contextualised or generic; and how would society agree upon the meaning or sense of that metaphor, are also questions that can be answered through research.

Research supports the concept of learners creating their own artefacts representing their own understanding (Papert, 1991; Artym et al., 2016; Prensky, n.d.). Due to time constraints, I created the milestones as examples of future visual communication curricula. As it is better to design products with people rather than for them (Parvin, 2013) and people now generate their own content (AIGA, 2017) a future direction for TOAOCP would be to have adolescents design and prototype their own high school textbooks independent of what platform the curriculum resides on. This undertaking of design would occur after establishing and collaborating on the set of milestones for TOAOCP (see Appendix A). The pictures used in the milestones were for learning computer programming and other lessons could be developed by considering these milestones as exemplars. The aim of this online picture system I am describing is to provide a framework for education purposes. The students could collaborate as they decide the meaning of the pictures and also decide how easy they are to understand. If an online environment were used to support the creation of these pictures, the pictures collectively would encompass a spirit of universality in learning as there would be no boundary or limit to the distribution and the contribution to it. The online environment would support collaboration with each other as well as other discipline groups. For example, the computer programming group could collaborate with an English literature group to integrate a narrative for the learning. How recognisable the pictures can be to learners could also be calculated as well as other measures. Like usefulness, the recognisability of a picture can be measured as a factor. Recognisability is important because it impacts universality and how a picture is understood from individual to individual.

Realism is a visual characteristic that impacts universality and may be measured along a continuum (see Chapter 4, Section 4.2.2). By universality I refer to the fact that TOAOCP successfully transferred knowledge to a majority of the participants (see Chapter 6, 6.2.1). Further research could begin to establish how universal this transferral of knowledge through pictures could be. By considering pictures along such a continuum, learners or curriculum designers could select an appropriate picture for a task. Students could create their own milestones like those in TOAOCP. The students could arrange, through graphic design techniques, pictures and type for their learning purposes. By sharing the creation of these works among students, the time taken required to produce curriculums like the milestones in TOAOCP (see Appendix A) would reduce. Pictures and curriculums could be discussed and improved within class room settings as well as in an online environment. By prompting every student to supply picture metaphors that represent the concepts they are acquiring, new ways of learning would be realised not to mention higher levels of knowledge transfer to the learners.

8.2.1 Sketch-noting

A high level of energy was evident among the participants in the focus group discussions surrounding the creation of their own milestones (see Chapter 6, Section 6.3.2). Along with the level of knowledge transfer achieved in the instrumentation (see Chapter 6, Section 6.2.1), this suggests future work is required in education training that includes graphic design techniques for learning centred around the picture. Teachers are often short of time, and many do not possess the necessary skills required to produce curriculums like those used within this thesis (see Appendix A). Live illustration and production of visual curriculums within class time alongside the teacher would be a beneficial experience for both teachers and students. Designers at many fortune 500 companies use sketching to communicate (Ngai, 2018). Visual scribing is a technique where a skilled creator develops a visual artefact in front of individuals to learn from. Scribing could occur while a school lesson takes place on a whiteboard at the front of the class. A skilled teacher with knowledge of the visual techniques listed within the literature review (see Chapter 4, Section 4.2.3) could facilitate central discussions held within a lesson. Visual characteristics (such as intention, attitudes, subjective norm, perceived behavioural control, clarity, cognition and motivation) could be rated by the same observed variables as those in TOAOCP (see Chapter 5, Section 5.5.1) within student work. Students would benefit significantly with visual scribing in class time as people remember up to six times more when pictures and text are paired together (Bunce, 2018). There are also digital platforms that support knowledge dissemination to teachers in niche areas that are outside the scope of the Australian National Curriculum such as Arts Live (The$_{songRoom}$, 2019) and Oracy (Incorporated, 2019). As these digital platforms exist and are in demand by the education community, it is possible that a platform for pictographic education like TOAOCP can also flourish.

Graphic design is the crafting of an interplay between word and image. Most teachers are unaware there exists ways to represent learning materials through graphic design. Educating teachers in visual communication would give them a tool to transfer more knowledge to their students particularly when this knowledge is complex such as TOAOCP. By using visual communication, a bridge between those who code and those who cannot was attempted and worked to the extent detailed in Chapter 6, Section 6.2. The reception from the staff participant faculty for TOAOCP was overwhelmingly positive as some of the teachers began to explain to me how they were using drawing actively in their lessons contributing way more information than I had requested from them. Teachers also were eager to select which milestones I would be creating during TOAOCP and assisted with the distribution of the instrumentation beyond what was necessary. Design is a value-adding learning tool for educators that as of yet remains relatively undiscovered within the education market.

Resources and workshops can be designed for teachers that can give them a fundamental understanding of graphic design and how to represent the learning of complexity through it. Although these resources and workshops have not been developed within TOAOCP, enough information exists within the literature review (see Chapter 4) to build these workshops in a minimum of time. Additionally, TOAOCP has developed means of measuring the effectiveness of the lessons. Initially when the teachers were approached to participate in TOAOCP, they were unaware that graphic design could be applied to learning computer programming. Therefore I would suggest that many teachers are unaware that graphic design is applicable to their respective disciplines.

Exposing adolescents to diagrammatic tools of cognition such as Tversky's tools of thought (see Chapter 4, Section 4.2.4) and allowing them class time to create their own learning materials based upon these forms would support the students' development of visual literacy. Through the application of graphic design principles listed in Chapter 4, such as realism and the Gestalt principles an adolescent could draw different types of pictures to enhance knowledge transfer (see Chapter 6, Section 6.2.1); assist their memory recall when learning (Wong, 2016b; Fernandes et al., 2018) along with attitude improvement (see Chapter 6, Section 6.1.3) and other benefits such as improving the intent to learn programming see Chapter 6, Section 6.1.3. In this way, the cognitive and motivational benefits achieved within Chapter 6, Section 6.1.7 can also be realised.

8.2.2 Suggestions for narrative design

In the future more hIstorical stories (see Chapter 6, Section 6.3.7) should be included in computer programming education to give a more holistic learning experience for the students. As narrative assists memory (Swain, 2014), historical stories about the developments of computer progrmming would enrich student learning beyond the features that I enquired about within the focus group discussions for TOAOCP. Intrinsic motivation, curiosity and plausibility are sustained through narrative (Dickey, 2011). Through combining story type elements within a visual curriculum, a richer learning experience can occur. As pictures were the initial novelty that enticed anticipation within TOAOCP participants, the comics maintained engagement through the narrative conveyed. Within TOAOCP, the participants were engaged, they spent time pondering the meaning of the pictures, cognitive load was lessened by the Z-path required for reading the comics, and their focus was enhanced.

8.2.3 Other measurements that could be included within the quantitative analysis

The link between classroom behaviour and motivation when learning computer programming through pictures is an area for future research. Curriculums designed like the instrumentation within TOAOCP could be used to support positive behaviour within the classroom.

Measuring the behavioural impacts of using a different type of curriculum in the classroom
Noted image theorist W.J.T. Mitchell, has called for a visual critique that is reflexive in nature (Asbjørn & Øyvind, 2006). Deconstructive sketching is an approach to understanding the relationship between drawing and meaning. By thinking through deconstructive sketching, a form of learning takes place that encourages understanding. Because of the energy and discussion that creating visual communication produces within the classroom setting, it is worth investigating the behavioural impacts starting with the students creating the visual curriculums themselves. Measuring the behavioural impacts within a classroom situation would include attitude changes in the participants, completion of set tasks within class time and how well groups function when learning through pictures.

Research has shown that students that struggle academically have poor behaviour within the classroom. The ability to impact motivation is also connected to maintaining better behaviour. Within TOAOCP motivation was influenced through the instrumentation (see Chapter 6, Section 6.1.7).

Visual rhetoric is also another impact that is measurable, as it is a triangular factor of the measures of logos, pathos and ethos. In the future, balancing these three characteristics of rhetoric, maximum meaning can be communicated by a designer to the learner through a visual form. In the quantitative research (see Chapter 6, Section 6.1), I learnt that the affects of graphic design upon learning are measurable. Because the focus groups revealed a lack of understanding of how pictures communicate, the anxiety produced in the participants could also be measured. A Likert scale exists for the measure of anxiety levels and worry (Morris et al., 1981) that could be adapted for TOAOCP. According to research from the ANU college of health and medicine, teachers are aware of the affects of anxiety upon the way students learn (ANU & Medicine, 2018).

Including a wider age range in the participant sample
Although primary school data was generally not included in the findings, pre-teens should participate in future studies. There was a significant difference in the role of pictures within learning from primary school to high school (see Chapter 6, Section 6.2.4). By examining a wider range of ages in the participant sample, the changes in the way a student learns can be understood from year to year for each student.

8.3 Summary

Chapter 8 addressed the limitations and future directions for TOAOCP. The limitations were addressed for both the quantitative and qualitative analysis. For both, the class time allocated for this research was limited. Within the quantitative analysis, the impacts measured could be widened to include anxiety and visual rhetoric. Although the quantitative data allowed measurement of the intervention of visual communication, this measurement did not explain the reasons why the impacts had occurred.

The demographic sample was confined to Perth metropolitan schools and rural schools were not considered within TOAOCP. The participant sample mostly considered Year 8 students only. By increasing the age range of the participants, more impacts as well as how these impacts change as a student gets older could be considered. The limitations in the qualitative analysis included the time constraint of 40 minutes and the fact there were some trivial comments within the focus group discussion sessions.

The future directions for TOAOCP include getting the participants to create their learning materials as well as a focus on the integration of graphic design techniques such as visual realism and the Gestalt principles within education at the teacher, policymaker and student level.

Chapter 9

Conclusion

9.1 Overview

This research aimed to communicate complexity to adolescents and to measure if pictures could positively affect this learning. If an educator requires a similar level of knowledge transfer that was achieved in TOAOCP (see Chapter 6, Section 6.2), then it would make sense to use a visual curriculum (see Appendix A) or a curriculum that has been created by a graphic designer. Although computer programming was the content, the project could be adapted across a range of different areas from physics to English literature and illustration. The adaption of a picture-based curriculum would support the principles of Universal Design for Learning (see Chapter 4, Section 4.3.7) and inclusivity. Within TOAOCP, pictures impacted the intent of adolescents to learn to program. Pictures, when created with the design techniques and principles as discussed in Chapter 4 such as appropriate consideration of visual realism, the Z-path arrangement and gestalt principles (see Chapter 4, Section 4.2.2, Section 4.2.1, Section 4.3.5), may provide a way forward to lessening information anxiety.

The conclusion to this thesis begins with a summary of the literature review. Then the methodology and findings are outlined to ground the reader in the topics covered so far, and lastly, the research questions are re-addressed.

9.2 Literature review summary

The literature review centred around three core themes: pictures, computer programming and learning. Design elements examined in TOAOCP were pictures and their arrangements in sequence, or, as comics. As the knowledge test (see Chapter 6, Section 6.2) was primarily a success for the majority of the participants, the graphic design theories of visual realism, the gestalt principles and the comics theory of the Z-path (see Chapter 4, Section 4.2.2, Section 4.3.7, Section 4.2.1) supported rhetoric and meaning-making. Within TOAOCP designed learning is in contrast to the rote processes that may take place in learning programming from traditional texts. Historical attempts at graphic design in computer programming documentation have largely been typocentric. De Almeida (2009) believes the designer has a responsibility over the content of the information (see Chapter 4, Section 4.2.3).

Pictures were discussed first as the core design element of TOAOCP (see Chapter 4, Section 4.2), and then their arrangement in picture assembly instructions (PAIs) was discussed from an engineering and instructional perspective. Pictures, in the form of PAIs, were explored for their suitability to represent computer programming. Diagrams, (that are pictures that often take the form of geometric shapes, lines and arrows) according to Tversky (2015) can be used as tools of thought and also represent complexity (see Chapter 4, Section 4.2.4).

Pictures placed in sequence or comics (see Chapter 4, Section 4.2.1) portray meaning and make sense to a learner (Cohn, 2014). By examining how pictures impact meaning or cognition for the participants, I was able to answer Research Question Two. The visual narrative that comes from placing pictures in a sequence was engaged the adolescents. A factor in the quantitative analysis was significant for the items supporting the narrative design (Strategy - see Chapter 6, Section 6.1.5) and the focus group data also revealed a high interest in narrative design from the node analysis performed with NVivo (see Chapter 6, Figure 6.23). Comics layouts were used in the milestones to emphasise the strategy and narrative design components measured in TOAOCP. Sequence along with selection and iteration was a fundamental component of TOAOCP, and this was a priori form that could be visually abstracted in all of the milestones. The findings in TOAOCP supported what was found in the literature review (see Chapter 4, Section 4.2.1) as a popular choice for conveying narrative.

I used visual hierarchy within the design of the milestones to organise thought and scaffold schematic process within the brain for the participants. The purpose of designing the milestones and using visual hierarchy was to lessen the cognitive load that the brain experiences when learning from a physical artefact.

Visual rhetoric was used within TOAOCP to persuade learning. Experienced visual learning designers know how to manipulate the characteristics (logic, ethics and emotion) of rhetoric for the desired affect of an artefact. According to Buchanan (1985), a design is successful when the characteristics of rhetoric are balanced. Visual rhetoric has an established history within the design of meaning (Van der Waarde, 2010; Kostelnick & Hassett, 2003; Joost & Scheuermann, 2007; Bonsiepe, 1965).

Flow theory was researched to be an optimum state where a viewer experiences immersion or total engagement in what they are doing (see Chapter 4, Section 4.3.6). The feeling of flow is what some designers use within their work and was a goal of the instrumentation of TOAOCP. The findings on flow were significant for to the participants' perceived understanding. When the participants learnt programming through the pictures in TOAOCP, they believed they understood the programming concepts. The participants perceived understanding contributed positively to being in flow (see Chapter 6, Section 6.1.5).

Few scholars have touched upon 'knowledge transfer' (see Chapter 6, Section 6.2) when researching comics (Mallia, 2007b; Caldwell, 2012; Jungst, 2007). The design of the instrumentation did have knowledge transfer for the participants. The arrangement of picture and text in a comic panel, allows two different types of realism (high and low) to occupy the same space (see Chapter 4, Figure 4.22). The participants supported the idea of learning through the pictures within TOAOCP (Chapter 6, Section 6.3.15). Support for the connection between visual perception and comic theory (Cohn, 2012, 2013) and new ways of seeing (Milano, 2018) has been alluded to by comics scholars. Visual perception in TOAOCP occurred through graphic design features such as visual realism and gestalt principles. I used pictures within the instrumentation to leverage visual perception in the participants, as a result, the participants were able to interpret the pictures successfully (CogniFit, 2018). As the instrumentation (see Appendix A) was successful to an extent (see Chapter 6, Section 6.2), the holistic design of the panels supported visual perception, promoting synaesthesia and enhancing understanding in TOAOCP. The synaesthetic effects (see Chapter 4, Section 4.3.3) experienced by the participants in TOAOCP stimulated the brain and maintained engagement with the instrumentation, to the extent that some of the participants refused to return the instrumentation as they were understanding the content and also enjoying learning in this way.

The discussion on computer programming in the literature review (see Chapter 4, Section 4.4) began by stating some of the issues of communicating the discipline. Screenshots that combine code and graphical user interfaces (see Chapter 4, Figure 4.2) dominate documentation within computer science. Although this may be changing, screenshots are still the primary means of visual communication. As software engineers write software documentation and are not trained in visual perception, software documentation is not likely to change, however maybe the way we communicate how software works can become more effective by using visual communication. The diagrams of computer science are often spatially arranged and in contrast to the time ordered sequence that programming occurs within. As these computer science diagrams are highly contextualised and rely on prior knowledge of how to read them, it is not always easy for the novice programmer to understand what the diagrams mean.

The *Measurement and theories of why people adopt a learning technology* section of the literature review (see Chapter 4, Section 4.5) addressed technology acceptance models (TAMs). The factors within the TAM for learning programming through pictures in TOAOCP (Usefulness, Fear, Fun and Enjoyment, Simplicity and Personal Ability) combine to form a students' attitudes towards intent to use pictures to learn computer programming (see Chapter 6, Section 6.1.3). The second set of attitude measures (see Chapter 4, Section 4.5.1) were combined to assess the intent to use comics to learn computer programming. The attitudes to learning programming through a comic improved from the pretest to posttest and the students felt they learned new information, were motivated and even experienced a flow state. Attitudes were positive toward learning programming through a comic by the participants after using the instrumentation. An additional set of factors (evaluation - see Chapter 6, Section 6.1.5) measured self-assessed cognition (SAC) and self-assessed motivation (SAM). Fun positively influenced cognition and motivation when learning programming through a comic. However fun failed to influence the actual test score (see Chapter 6, Section 6.1.5). The prior knowledge of the participants worked against the actual test score. In other words, the more prior knowledge a participant had of programming, the less successful they were in the programming knowledge test. Therefore the instrumentation in TOAOCP was best suited to the majority of the class and not those few that have already experienced learning programming languages.

As discussed in the conclusion of the literature review (see Chapter 4, Section 4.6), the impacts of learning programming through a comic were measured. As was found in the results, understanding was strong(see Chapter 6, Section 6.15) supporting current research concerning cognition and learning through pictures in sequence (see Chapter 4, Section 4.2.1).

9.3 Methodology and findings summary

Responses to the quantitative survey comprised of 59 adolescents; 21 males and 38 females. The age breakdown was three 12 years old, 51 thirteen years old, and five 14 years old adolescents from within Year 8 technology classes. The methodology adapted the technology acceptance models into two visual communication acceptance models, one for pictures and one for comics. After the quantitative data was analysed from the models, the data were triangulated with two focus group discussion sessions. Within TOAOCP, factors were adapted from a model based upon the theory of reasoned action (TRA) and used to measure impacts upon the adolescents. The acceptance models were constructed to measure significant changes in impacts upon intent to learn computer programming. Attitudes were also measured as these reflected the beliefs and values the participants had about learning. Structural equation modelling (SEM) was used to calculate the impacts of using pictures upon a learner's perceived cognition (SAC) and their perceived motivation (SAM) (see Chapter 6, Section 6.1.7). Separate SEMs were constructed to answer the research questions.

9.3.1 Answering the research questions

The students anticipated they would have fun and that the pictures would be simple to learn programming through (t0) (see Chapter 7, Section 6.1.3). They anticipated that learning through the pictures would be fun, make the lesson more interesting and that they would like learning programming (see Chapter 5, Table 5.4, *items 1.7, 1.8 and 1.9*).

They also believed that learning programming through the pictures would be simple because learning with pictures would be easy (1.4), they would be good at learning with pictures (1.5) and it would be easy to learn programming through pictures (see Chapter 5, Table 5.4, *items 1.4, 1.5 and 1.6*). After using the comic, the usefulness, representation and motivation, as well as the participants being in flow when using the artefact, impacted significantly upon the participants' self-assessed cognition of the learning comic (see Chapter 6, Section 6.1.7). These impacts were the affects that answered Research Question One. Therefore the pictures helped participant understanding and learning of programming in a number of ways because they were useful, represented concepts easily, motivated and contributed to the learners being in a flow state.

The participants' motivation for using pictures to learn programming was also positively impacted after using the instrumentation. They were motivated to learn programming concepts through the pictures because they believed they understood programming from them. The model constructed to answer Research Question Two (see Chapter 6, Figure 6.8) measured perceived cognition, picture literacy, personal ability and picture representation as impacting the participant's motivation to learn computer programming through pictures (see Chapter 7, Section 7.2).

The anticipation of the participants, that they would have fun learning through the pictures, was helpful before using the instrumentation. It took minimal effort to entice the participants to take part in the programming lesson. However, the lesson was a learning experience from the participants' perspective, and they realised that there were features and characteristics related to visual communication that were unfamiliar. Although there were many positive impacts upon the intent to learn programming from both the pictures (see Chapter 6, Section 6.1.9) and the comics (see Chapter 6, Section 6.1.9), after the lesson, the participants did not feel that pictures were as simple and fun as they had anticipated (see Chapter 6, Table 6.5). Before the data analysis, I had believed that the participants were more conversant with pictures. The non-significance of the pre and posttest attitudes for pictures was disappointing; however, these adolescents had no familiarity with visual discourse or an understanding that pictures can communicate. The discussions within the focus groups further reinforced the unfamiliarity (see Chapter 6, Section 6.3.12). The conclusion here is that there was a general lack of discourse concerning picture communication and these participants were aware of the lack because of the number of questions that they asked during the focus group discussions.

Despite this lack of discourse to describe pictures, the participants were far more confident of the affects when pictures were placed in sequence. After the use of the comic, usefulness (see Chapter 6, Section 6.1), simplicity (see Chapter 7, Section 6.2) and ability (see Chapter 6, Section 6.3) emerged as impacts instead of fun on its own. Given the choice, participants' would intend to use comics in the future to learn programming. The participants believed the comic to be useful and simple to learn programming through. Using the comic positively impacted the participants' belief about their personal ability to program. Males would intend to learn programming through a comic more than the females and were also more concerned with what the pictures meant (Chapter 6, Figure6.21).

The attitudes towards the pictures and comics were the combination of usefulness, simplicity, fear, fun and personal ability (see Chapter 6, Figures 6.4, 6.5). To answer Research Question Three, the attitudes towards pictures and comics were each summarised, and then a regression was calculated against the intent (see Chapter 6, Figures 6.4, 6.5). The attitudes towards learning programming from pictures upon intent were positively impacted after the treatment. The attitudes towards intent to learn programming from comics were also positively impacted after the treatment. The use of both pictures and comics to learn programming had a positive affect on the beliefs and values of the participants.

As well as measuring the attitudes, several hypotheses helped to answer Research Question Three. As TOAOCP is a unique and preliminary study, the hypotheses established will provide data for future and similarly visually designed interventions (see Chapter 4, Section 4.5.5). As there were two sets of data collected, one for pictures and one for comics, the hypotheses are discussed below in two separate groups. The six hypotheses regarding participant understanding of the function and effectiveness of pictures are now re-addressed:

> H1p: Participants who intend to learn computer programming more, also report the pictures as being more useful.

Within TOAOCP perceived usefulness of pictures was defined as the degree to which a participant believed that the pictures enhanced their learning (see Chapter 4, Section 4.5.3). Intent was defined as the intention of a learner to use a given system or artefact (see Chapter 4, Section 4.5.1). The more useful the participants believed the pictures to be, the more they intended to use pictures to learn programming through.

> H2p: Participants who find the pictures to be more useful, also report having more fun and enjoyment when learning computer programming.

How learners perceive and make use of pictures can theoretically come from more general beliefs and psychology of learning. Pictures are thought-generating devices and technology of their own (see Chapter 4, Section 4.2.4). Technology acceptance models (TAMs) suggest that an expectation to work with a technology that is useful and fun is a predictor of intent to use that technology (Venkatesh et al., 2003). This hypothesis (H2p) finding aligns with the Venkatesh et al. (2003) findings and is significant because research connecting the fun experienced by a learner and programming documentation is scant.

> H3p: Participants that have more fun when learning computer programming through pictures, have less fear of it.

Fear in TOAOCP emerged in the participants as a lack of understanding of how to interpret the meaning of pictures. This was evident from the focus group discussions (see

Chapter 6, Section 4.5.3 and 6.3.12). However, the more fun a participant experiences when viewing the pictures, the less fear they have of learning programming through them.

> H4p: Participants that find they have more prior knowledge about computer programming, believe the pictures to be more useful.

Activating the participants' prior knowledge influences how useful they believe the pictures within TOAOCP were. There exists conflicting findings upon prior knowledge and what role images play in learning. The TOAOCP hypothesis contrasts with some findings upon the activation of prior knowledge and learning media. For example, within design principles for dynamic visualisations, learning is enhanced when essential information is represented in pictorial form rather than in textual form (Plass et al., 2009). The findings from Plass et al. (2009) appear to apply to materials that are complex and induce high cognitive load. Lee, Plass, and Homer (2006) and Plass et al. (2009) findings apply to learners with low prior knowledge in the subject matter communicated in the media, namely animations and simulations. Ideally, the pictures within TOAOCP should assist learners with low prior knowledge in the subject matter and act as a vital scaffolding tool for the knowledge of computer science. Students educated on concepts such as devices of thought (see Chapter 4, Section 4.2.4) would rely less on prior knowledge when interpreting pictures.

> H5p: Participants with more understanding of the pictures about programming, also rely more on their prior knowledge.

Although this hypothesis would initially seem to be acting in reverse to the main aim of this thesis, it did, in fact, highlight comments within the focus group discussions. The participants were relying on existing programming knowledge for help with understanding the pictures. The participants were not confident enough to interpret the meanings of pictures when viewing a single picture. Here, existing knowledge was relied upon by the participants. I would expect this hypothesis to alter with students that have high visual literacy. Although I did not measure the level of visual literacy in these students, I suspect that the level of the participants was not very high. Participants would rely less on their prior computer science knowledge if they had existing visual literacy when entering the experiment.

> H6p: Participants with more motivation when learning programming through the pictures, also report understanding programming more.

Much research exists extolling the relationship between motivation and cognition in student learning (Zheng et al., 2018; Stolk & Harari, 2014; Walker et al., 2006). A student's intrinsic motivation increases the more they believe they understand pictures. Again prior knowledge or a pre-existing visual literacy in the participants would enhance motivation greatly and support the new knowledge acquired from the instrumentation within TOAOCP.

> H7p: Participants with more ability to learn programming through pictures, also report they understand the pictures more.

H7p has theoretical roots in Bandura's social cognitive theory (see Chapter 4, Section 4.5.4). An individual's self-worth or belief concerning their ability about programming is influenced by how well they think they understand the pictures. Participants could not easily explain how pictures helped them to understand programming; however, when pictures were placed in a sequence, the participants managed to explain their understanding.

As data were analysed to evaluate the comic, the hypotheses regarding participant understanding of the function and effectiveness of comics will now be reviewed and summarised.

> H1c: Participants with more intent to learn programming through a comic, also report higher belief in their personal ability to program.

As a participant's intent to learn programming through a comic increased, their personal ability in programming improved. In this way learning programming through a comic would give the student the same knowledge as learning with another style of media. The more participants intended to learn through a comic, the better programmer they believed themselves to be. H1c also has philosophical roots in Bandura's theory. Intent and personal ability have been found to impact each other in a wide range of studies from breast health and intent to have a mammogram (Champion et al., 2005) to STEM education and intent to influence career choices in adolescents (Wagstaff, 2014). Champion et al. (2005) proved that women with high self-efficacy were more likely to seek a mamogram post intervention while Wagstaff (2014) concluded that a student's science self-efficacy influenced their future career intent to engage in a career in science and technology. Within TOAOCP, intent to learn programming through a comic increased the participants intent to consider computer programming as a career choice in the future (see Chapter 6, Section 6.1.9).

> H2c: Participants with more personal ability, also report placing more importance on what friends and family think of them learning through a comic.

The subjective norm is a set of beliefs that caregivers, family and friends have concerning a proposed behaviour. Within TOAOCP the proposed behaviour was learning computer programming through a comic. The three impacts of attitude, self-efficacy and the subjective norm, can determine the intent of a student to learn through an artefact. Certain beliefs of adolescents have been shown to be impacted by the subjective norm (Schouten et al., 2007). In a study by Schouten et al. (2007) concerning parent-adolescent communication about sexuality, the participants' beliefs were significantly predicted by the subjective norm. Within TOAOCP what parents, friends and family thought of a participant learning programming through a comic did influence a participant's belief in their own personal ability concerning programming.

> H3c: Participants with more understanding of pictures when read in sequence, also report having higher belief in their personal programming ability.

Strategy measured the readability and navigation, or ease of following information within the Z-path (see Chapter 4, Section 4.2.1), in the instrumentation for the participants of TOAOCP (see Chapter 4, Section 4.5.4). It would seem that the information within the instrumentation was indeed easy to follow and contributed positively to how the participants felt concerning their own programming ability.

> H4c: Participants with more strategy, report having lower fear of learning programming through a comic.

H4c concerned how easily the participants navigated the comic when learning programming from it (see Chapter 5, Section 5.2). The navigation in the comic concerned the order in which the pictures were read (see Chapter 4, Section 4.2.1). Strategy influences how comfortable participants feel when learning programming from comics. If they felt comfortable with the layout there was no fear in interpreting the visual communication and pictures within the instrumentation (see Chapter 6, see Section SEMComicModel). Academic literature espouses that the eyes follow a path when reading a comic (Cohn, 2014) and that this enhances comprehension (Foulsham et al., 2016b; Cohn, 2018; Foulsham et al., 2016a).

> H5c: Male and female individuals differ in their intent to learn programming through a comic.

Studies have found that males have a stronger preference for reading comics than females do (Merisuo-Storm, 2006; Appleyard & Appleyard, 2009; Branch, 2018). Despite the evidence that males prefer comics, the first focus group was a single-sex girls school, and they were adamant that the instrumentation was useful for them and that the pictures were useful (see Chapter 6, Section 6.3.15). There are two reasons why the results in this all girl group were different from the norm of boys having a greater preference for comics. Firstly, the school was unique in that the participants were all female and they had a female information technology teacher. When girls have a female teacher in a discipline they are studying, they are more like to consider that discipline as something they would do (Zendler & Hubwieser, 2013). Secondly, the teacher of this all girl group, had previously sought visual communication materials to teach the girls. Therefore the girls did not think learning from a comic was something different and may actually prefer the comic as a school text.

> H6c: Participants that care more about what their friends and family think about learning computer programming from a comic, also report higher belief in their ability to learn from a comic.

H6c connects the opinions of people that are important to the participant, directly to how well they process the information in the comic. The subjective norm (see Chapter 4, Section 4.5.1) affects the focus the participant devotes to reading the comic and learning programming from the comic.

> H7c: Participants that are older, report caring less about what their friends and family think about learning computer programming through a comic.

H7c supported the notion that as the participants get older how they learn is less affected by what people that are important to them think. Other studies have also found the measure of age moderated the subjective norm of the participants (Morris & Venkatesh, 2000). The Morris and Venkatesh (2000) study on acceptance of new technology for work purposes, proposed that gaining a better theoretical understanding of age difference within the participants was essential in order to introduce the new technology. Within TOAOCP, the subjective norm impacted the younger participants most significantly.

The above hypotheses (Hp1 - Hc7) also provide the relationships between the impacts for Research Question Three. Participant attitudes that stem from beliefs and values were positively impacted after using a comic to learn computer programming (see Chapter 7, Section 7.3).

Three types of cognition were measured by quantitative analysis during TOAOCP (see Chapter 4, see Section 4.5.4). The majority of participants scored 66% in the knowledge test for actual cognition. Self-assessed cognition was the participant's own belief in how much they understood the programming concepts. The perceived picture and comic cognition were how well participants believed they understood the pictures and the comic, broken down into separate scores. There was an impact upon flow from both picture and comic understanding and the actual cognition. Both males and females believed the learning experience could improve with the incorporation of narrative design and gamification elements.

9.4 Concluding remarks

Within computer programming, screenshots dominate the technical documentation, and these images do not contribute to perceptual reasoning. Pictures created by a designer that are distilled and abstracted from reality (see Chapter 4, Section 4.2.4) cue processes in the brain that encourage sense-making. Illustrations or drawings can be constructed to help organise ideas and mental schema. A person skilled in visual communication can help portray complexity to a learner, rather than relying on screenshots. Drawing occupies a central place within visual communication for learning and its representation.

Visual communication should make that which 'can not be seen' (Scott McCloud's third type of vision) and where learning is concerned, understood. Because TOAOCP affected intent to learn programming (see Chapter 6, Section 6.1.9), I also hope this research encourages a more significant emphasis on visual literacy within formal education systems. A starting point would be to implement the accompanying milestones (see Appendix A) within formal education systems or using the milestones as exemplars to create curriculums for adolescents.

Pictures can be classified according to their fidelity to a referent in the real world. They can be arranged, conceptually, along a ’realism continuum’ from highly realistic (such as a colour photograph) at one end through to an abstracted symbol at the other end (such as a pictogram in an airport signage system). I distilled the pictures for meaning-making reasons in TOAOCP. This project evaluated pictures, and the data collected provided support that the design of the pictures used in the instrumentation had communicated successfully. The intent to learn programming through the pictures was affected (see Chapter 6, Section 6.1.9). The actual knowledge transfer was also successful to approximately 70% of the class (see Chapter 7, Section 6.2.1). The many reasons for why intent and knowledge transfer were impacted, were researched in the literature review under visual realism (Chapter 4, 4.2.2).

I have hoped to shed some light upon the communicative abilities of pictures where programming is concerned. I am hoping that this research serves to articulate the necessary role visual designers play in the communication of complexity.

TOAOCP examined two specific areas of visual communication. The first was a fundamental element and cornerstone of graphic design, the picture. The second area examined within the research was the arrangement of those pictures in sequence as comics. The pictures and comics within TOAOCP were designed to utilise a specific sequential order that is suited to the transformation of information. The dual coding nature (see Chapter 4, Figure 4.15) of comics emphasises both the picture and text elements. The type of textual realism within TOAOCP was programming code. These two types of realism, visual and textual (Chapter 4, Section 4.2.2) when combined in the same space (see Chapter 4, Figure 4.22) bring a holistic type of communication to programming. TOAOCP is a learning tool to understand complexity. The visual realism used within this research, proved to be an essential tool for understanding both the concepts and relationships within computer programming for adolescents. The use of pictures in the learning materials for the students, as opposed to the convention of text in conventional programming curricula, improved student attitudes. Pictures, especially when placed in sequence, are more likely to capture the attention and imagination of students who wouldn’t normally be heading towards a life in programming. Through using pictures to teach an adolescent to program, more adolescents may consider a career in the programming discipline that will address the programming shortage crisis (see Chapter 2, Section 2.3).

Appendix A

List of Attachments

- Milestone one: 1950smilestoneTOAOCP.pdf
- Milestone two: 1960smilestoneTOAOCP.pdf
- Milestone three: 1970smilestoneTOAOCP.pdf
- Milestone four: 1980smilestoneTOAOCP.pdf
- Milestone five: 1990smilestoneTOAOCP.pdf
- Milestone six: 2000smilestoneTOAOCP.pdf
- InstrumentationTOAOCP.pdf
- FocusGroup3000TOAOCPt.pdf
- FocusGroup3000TOAOCPp.pdf
- FocusGroup6000TOAOCPt.pdf
- FocusGroup6000TOAOCPp.pdf

Appendix B

Scale adaption

TABLE B.1: Scale adaption

Factor	Items	TOAOCP adapted items	
Attitudes (TAM) Iten et al., (2014)		**Picture adaption**	**Comic adaption**
Usefulness	'I can learn better with learning games.' 'I can learn facts faster with learning games.' 'When learning with learning games, I will probably get better marks.'	'I learn better with pictures.' 'I learn facts faster with pictures.' 'When learning with pictures, I will probably understand it better.'	'I learn computer programming better with comics.' 'I learn computer facts faster with comics.' ' When learning with comics, I will probably understand computer programming better.'

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Factor	Items	TOAOCP adapted items	
Attitudes (TAM) Iten et al., (2014)		**Picture adaption**	**Comic adaption**
Simplicity	‘Using learning games would be easy for me.’ ‘I would be good at using learning games.’ ‘It would be easy for me to learn how to play learning games.’	‘Learning with pictures would be easy for me.’ ‘I would be good at learning with pictures.’ ‘It would be easy for me to learn computer programming with pictures.’	‘Learning computer programming with comics would be easy for me.’ ‘I would be good at learning computer programming with comics.’ ‘It would be easy for me to learn programming with comics.’
Fun and Enjoyment	‘Learning with learning games is fun.’ ‘Learning games make learning more interesting.’ ‘I like using learning games.’	‘Learning with pictures is fun.’ ‘Learning with pictures makes the lesson more interesting.’ ‘I like learning with pictures.’	’Learning computer programming with comics is fun.’ ’Learning with comics makes the programming lesson more interesting.’ ’I like learning computer programming with comics.’
Subjective Norm	‘My friends would like if I got involved with learning games.’ ‘My parents and my family would like if I got involved with learning games.’		‘My friends would like if I learnt through this type of comic.’ ‘My parents would like if I learnt through this type of comic.’ ‘My family would like if I learnt through this type of comic.’

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Factor	**Items**	**TOAOCP adapted items**	
Attitudes (TAM) Iten et al., (2014)		**Picture adaption**	**Comic adaption**
Personal Ability	'I would be able to learn with a learning game even if nobody was there to help me.' 'If I had enough time to find out how it works, I would be able to learn with a learning game even without help or instructions.' 'I know enough about learning games to learn them on my own.'	'I would be able to learn with pictures even if nobody was helping me.' 'Given time I can work out pictures without instructions to help me.' 'I know enough about pictures to study on my own.'	'I would be able to learn computer programming with comics even if nobody was helping me.' 'Given time I can work out computer programming without a comic about programming to help me.' 'I know enough about comics to use them to study computer programming on my own.'
Fear	'I'm afraid I might break something on the computer while playing.' 'I'm afraid I might delete something on the computer because I click the wrong button when playing.' 'I don't like learning with learning games because I'm afraid of making mistakes which I cannot correct.'	'I'm afraid I will not understand the pictures in the lesson.' 'I'm afraid I will misinterpret the pictures in the lesson.' 'I'm afraid I will make a mistake in the lesson because of the pictures.'	'I'm afraid I might break/rip the comic in the lesson.' 'I'm afraid I might turn to the wrong page in lesson.' 'I'm afraid I will not understand the lesson.'

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Factor	Items	TOAOCP adapted items	
Attitudes (TAM) Iten et al., (2014)		**Picture adaption**	**Comic adaption**
Intent to Use	'I expect to learn something in the next month with learning games.' 'I think I will learn something in the next six months with learning games.' 'I want to use more often learning games.'	'I expect to learn something about computer programming if I use pictures.' 'If I experience a lesson on computer programming in the next few months, I think I will learn something.' 'I want to use pictures more often when I learn computer programming.'	'I expect to learn something about programming in the future if I learn with comics.' 'I think I will learn something in the future about programming.' 'I want to use comics more often when I learn.'
Evaluation			
Prior Knowledge	'To play the game, it was important that you knew a lot about the Internet.' 'To get a lot of points I needed to know a lot about the Internet.' 'To improve, I have to learn more about the Internet.'	'To complete the lesson it was important that you know a lot about programming.' 'To get through the lesson it was important that you know about programming.' 'To get through this lesson I need to know more about programming.'	
Flow	'While playing, I was only thinking about the game.' 'While playing, I forgot everything else around me.' 'While playing, I didn't realise how the time passed.'	'In the lesson, I was thinking only about the learning from it.' 'In the lesson, I forgot things going on around me.' 'In the lesson, time went quickly.'	

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Factor	Items	TOAOCP adapted items	
Attitudes (TAM) Iten et al., (2014)		**Picture adaption**	**Comic adaption**
Self-Assessed Cognition	‘In the game, I learned about what kind of information on the Internet is good.’ ‘In the game, I learned about what kind of websites I should avoid.’ ‘Because of the game I’m more aware of how to recognise risks in the Internet.’	’In the lesson I learnt about programming.’ ’In the lesson I learnt I should avoid programming.’ ’Because of this lesson I am more confident about programming.’	
Self-Assessed Motivation	‘The game increased my interest in the Internet.’ ‘While playing the game I realised, I would like to learn more about how to differentiate between good and bad websites.’ ‘Because of the game I will be more careful when using the Internet.’	‘ The lesson increased my interest in programming.’ ‘ Whilst in the lesson I would like to learn more about programming.’ ‘ Because of the lesson, I am more aware of programming concepts.’	

Appendix C

Descriptive statistics

TABLE C.1: Descriptive Statistics for Pictures (Attitudes factors)

	N	Mean	Std. Deviation	Minimum	Maximum
UsefulnessPreTest1.1Pictures	59	3.698	1.2910	1.0	5.0
UsefulnessPreTest1.2Pictures	59	3.766	.9897	1.0	5.0
UsefulnessPreTest1.3Pictures	59	3.917	.8158	2.0	5.0
SimplicityPreTest1.4Pictures	59	3.863	.8189	2.0	5.0
SimplicityPreTest1.5Pictures	59	3.919	.8968	2.0	5.0
SimplicityPreTest1.6Pictures	58	3.302	1.1620	1.0	5.0
FunEnjoymentPreTest1.7Pictures	59	3.812	1.0432	1.0	5.0
FunEnjoymentPreTest1.8Pictures	59	3.685	1.2013	1.0	5.0

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	N	Mean	Std. Deviation	Minimum	Maximum
FunEnjoymentPreTest1.9Pictures	59	4.017	.9000	1.0	5.0
PersonalAbilityPreTest1.10Pictures	59	3.525	1.1501	1.0	5.0
PersonalAbilityPreTest1.11Pictures	59	3.610	1.0670	1.0	5.0
PersonalAbilityPreTest1.12Pictures	59	3.322	1.1954	1.0	5.0
FearOfUsePreTest1.13Pictures	59	2.949	1.2377	1.0	5.0
FearOfUsePreTest1.14Pictures	59	2.949	1.1511	1.0	5.0
FearOfUsePreTest1.15Pictures	59	2.898	1.1401	1.0	5.0
IntentionToUsePreTest1.16Pictures	59	3.542	.9344	1.0	5.0
IntentionToUsePreTest1.17Pictures	59	3.559	1.0047	1.0	5.0
IntentionToUsePreTest1.18Pictures	59	3.576	1.0700	1.0	5.0
UsefulnessPostTest1.1Pictures	59	3.763	1.0882	1.0	5.0
UsefulnessPostTest1.2Pictures	59	3.797	1.0302	1.0	5.0
UsefulnessPostTest1.3Pictures	59	3.898	1.0119	1.0	5.0
SimplicityPostTest1.4Pictures	59	3.898	.9039	2.0	5.0
SimplicityPostTest1.5Pictures	59	3.814	.8997	2.0	5.0
SimplicityPostTest1.6Pictures	59	3.559	1.0384	1.0	5.0
FunEnjoymentPostTest1.7Pictures	59	3.814	.9733	1.0	5.0
FunEnjoymentPostTest1.8Pictures	59	3.847	1.0308	1.0	5.0
FunEnjoymentPostTest1.9Pictures	59	3.949	1.0073	1.0	5.0

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	N	Mean	Std. Deviation	Minimum	Maximum
PersonalAbilityPostTest1.10Pictures	59	3.519	1.0545	1.0	5.0
PersonalAbilityPostTest1.11Pictures	59	3.605	.9639	1.0	5.0
PersonalAbilityPostTest1.12Pictures	59	3.419	1.0352	1.0	5.0
FearOfUsePostTest1.13Pictures	59	2.995	1.2282	1.0	5.0
FearOfUsePostTest1.14Pictures	59	2.927	1.1385	1.0	5.0
FearOfUsePostTest1.15Pictures	59	2.925	1.1820	1.0	5.0
IntentionToUsePostTest1.16Pictures	59	3.653	.9924	1.0	5.0
IntentionToUsePostTest1.17Pictures	59	3.793	.9784	1.0	5.0
IntentionToUsePostTest1.18Pictures	59	3.769	1.0686	1.0	5.0

TABLE C.2: Descriptive Statistics for Pictures (T-test)

Ranks		**N**	**Mean Rank**	**Sum of Ranks**
UsefulnessPostTest1.1Pictures - UsefulnessPreTest1.1Pictures	Negative Ranks	14	14.82	207.50
	Positive Ranks	16b	16.09	257.50
	Ties	29c		
	Total	59		
UsefulnessPostTest1.2Pictures - UsefulnessPreTest1.2Pictures	Negative Ranks	15d	14.63	219.50
	Positive Ranks	15e	16.37	245.50
	Ties	29f		
	Total	59		
UsefulnessPostTest1.3Pictures - UsefulnessPreTest1.3Pictures	Negative Ranks	13g	21.15	275.00
	Positive Ranks	20h	14.30	286.00
	Ties	26i		
	Total	59		
SimplicityPostTest1.4Pictures - SimplicityPreTest1.4Pictures	Negative Ranks	14j	15.57	218.00
	Positive Ranks	16k	15.44	247.00
	Ties	29l		
	Total	59		
SimplicityPostTest1.5Pictures - SimplicityPreTest1.5Pictures	Negative Ranks	19m	19.11	363.00
	Positive Ranks	16n	16.69	267.00
	Ties	24o		

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Ranks		N	Mean Rank	Sum of Ranks
	Total	59		
SimplicityPostTest1.6Pictures - SimplicityPreTest1.6Pictures	Negative Ranks	15p	15.60	234.00
	Positive Ranks	20q	19.80	396.00
	Ties	23r		
	Total	58		
FunEnjoymentPostTest1.7Pictures - FunEnjoymentPreTest1.7Pictures	Negative Ranks	15s	17.67	265.00
	Positive Ranks	17t	15.47	263.00
	Ties	27u		
	Total	59		
FunEnjoymentPostTest1.8Pictures -	Negative Ranks	13v	13.73	178.50
	Positive Ranks	18w	17.64	317.50
	Ties	28x		
	Total	59		
FunEnjoymentPostTest1.9Pictures - FunEnjoymentPreTest1.9Pictures	Negative Ranks	15y	15.17	227.50
	Positive Ranks	13z	13.73	178.50
	Ties	31aa		
	Total	59		
PersonalAbilityPostTest1.10Pictures - PersonalAbilityPreTest1.10Pictures	Negative Ranks	19ab	14.55	276.50
	Positive Ranks	14ac	20.32	284.50

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Ranks		N	Mean Rank	Sum of Ranks
	Ties	26ad		
	Total	59		
PersonalAbilityPostTest1.11Pictures -	Negative Ranks	17ae	14.47	246.00
	Positive Ranks	14af	17.86	250.00
	Ties	28ag		
	Total	59		
PersonalAbilityPostTest1.12Pictures - PersonalAbilityPreTest1.12Pictures	Negative Ranks	17ah	17.47	297.00
	Positive Ranks	19ai	19.42	369.00
	Ties	23aj		
	Total	59		
FearOfUsePostTest1.13Pictures - FearOfUsePreTest1.13Pictures	Negative Ranks	14ak	19.04	266.50
	Positive Ranks	19al	15.50	294.50
	Ties	26am		
	Total	59		
FearOfUsePostTest1.14Pictures - FearOfUsePreTest1.14Pictures	Negative Ranks	17an	19.53	332.00
	Positive Ranks	18ao	16.56	298.00
	Ties	24ap		
	Total	59		
FearOfUsePostTest1.15Pictures -	Negative Ranks	16aq	17.81	285.00

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Ranks		N	Mean Rank	Sum of Ranks
	Positive Ranks	18ar	17.22	310.00
	Ties	25as		
	Total	59		
IntentionToUsePostTest1.16Pictures - IntentionToUsePreTest1.16Pictures	Negative Ranks	14at	21.93	307.00
	Positive Ranks	23au	17.22	396.00
	Ties	22av		
	Total	59		
IntentionToUsePostTest1.17Pictures - IntentionToUsePreTest1.17Pictures	Negative Ranks	12aw	18.63	223.50
	Positive Ranks	23ax	17.67	406.50
	Ties	24ay		
	Total	59		
IntentionToUsePostTest1.18Pictures – IntentionToUsePreTest1.18Pictures	Negative Ranks	13az	18.23	237.00
	Positive Ranks	20ba	16.20	324.00
	Ties	26bb		
	Total	59		

TABLE C.3: Descriptive Statistics for Comics (Attitudes factors)

	N	Mean	Std. Deviation	Minimum	Maximum
UsefulnessPreTest2.1Comics	59	3.305	1.1181	1.0	5.0
UsefulnessPreTest2.2Comics	59	3.186	1.1667	1.0	5.0
UsefulnessPreTest2.3Comics	59	3.254	1.1536	1.0	5.0
SimplicityPreTest2.4Comics	59	3.229	.9752	1.0	5.0
SimplicityPreTest2.5Comics	59	3.297	.9654	1.0	5.0
SimplicityPreTest2.6Comics	59	2.983	1.1521	1.0	5.0
FunEnjoymentPreTest2.7Comics	59	3.254	1.1976	1.0	5.0
FunEnjoymentPreTest2.8Comics	59	3.390	1.2037	1.0	5.0
FunEnjoymentPreTest2.9Comics	59	3.458	1.1495	1.0	5.0
PersonalAbilityPreTest2.10Comics	59	3.305	1.0868	1.0	5.0
PersonalAbilityPreTest2.11Comics	59	3.271	1.0311	1.0	5.0
PersonalAbilityPreTest2.12Comics	59	3.237	.9885	1.0	5.0
FearOfUsePreTest2.13Comics	59	2.890	1.4235	1.0	5.0
FearOfUsePreTest2.14Comics	59	2.898	1.4227	1.0	5.0
FearOfUsePreTest2.15Comics	59	3.203	1.3102	1.0	5.0
IntentionToUsePreTest2.16Comics	59	3.305	1.1634	1.0	5.0
IntentionToUsePreTest2.17Comics	59	3.695	1.1485	1.0	5.0
IntentionToUsePreTest2.18Comics	59	3.254	1.3077	1.0	5.0
UsefulnessPostTest2.1Comics	59	3.607	1.1289	1.0	5.0

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	N	**Mean**	**Std. Deviation**	**Minimum**	**Maximum**
UsefulnessPostTest2.2Comics	59	3.431	1.0686	1.0	5.0
UsefulnessPostTest2.3Comics	59	3.407	1.1004	1.0	5.0
SimplifyPostTest2.4Comics	59	3.578	1.0026	1.0	5.0
SimplifyPostTest2.5Comics	59	3.441	1.0217	1.0	5.0
SimplifyPostTest2.6Comics	59	3.153	1.2292	1.0	5.0
FunEnjoymentPostTest2.7Comics	59	3.183	1.3355	1.0	5.0
FunEnjoymentPostTest2.8Comics	59	3.436	1.1810	1.0	5.0
FunEnjoymentPostTest2.9Comics	59	3.586	1.2599	1.0	5.0
PersonalAbilityPostTest2.10Comics	59	3.624	1.1423	1.0	5.0
PersonalAbilityPostTest2.11Comics	59	3.464	1.1006	1.0	5.0
PersonalAbilityPostTest2.12Comics	59	3.268	1.2691	1.0	5.0
FearOfUsePostTest2.13Comics	59	2.725	1.3846	1.0	5.0
FearOfUsePostTest2.14Comics	59	2.497	1.2808	1.0	5.0
FearOfUsePostTest2.15	59	2.851	1.2981	1.0	5.0
IntentionToUsePostTest2.16Comics	59	3.342	1.3334	1.0	5.0
IntentionToUsePostTest2.17Comics	59	3.612	1.1591	1.0	5.0
IntentionToUsePostTest2.18Comics	59	3.431	1.3145	1.0	5.0

TABLE C.4: Descriptive Statistics for Comics (T-test)

Ranks		**N**	**Mean Rank**	**Sum of Ranks**
UsefulnessPostTest2.1Comics - UsefulnessPreTest2.1Comics	Negative Ranks	10a	14.20	142.00
	Positive Ranks	21b	16.86	354.00
	Ties	28c		
	Total	59		
UsefulnessPostTest2.2Comics - UsefulnessPreTest2.2Comics	Negative Ranks	10d	19.55	195.50
	Positive Ranks	23e	15.89	365.50
	Ties	26f		
	Total	59		
UsefulnessPostTest2.3Comics - UsefulnessPreTest2.3Comics	Negative Ranks	14g	18.00	252.00
	Positive Ranks	21h	18.00	378.00
	Ties	24i		
	Total	59		
SimplifyPostTest2.4Comics - SimplicityPreTest2.4Comics	Negative Ranks	11j	18.68	205.50
	Positive Ranks	27k	19.83	535.50
	Ties	21l		
	Total	59		
SimplifyPostTest2.5Comics - SimplicityPreTest2.5Comics	Negative Ranks	13m	15.88	206.50
	Positive Ranks	19n	16.92	321.50
	Ties	27o		

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Ranks		N	Mean Rank	Sum of Ranks
	Total	59		
SimplifyPostTest2.6Comics - SimplicityPreTest2.6Comics	Negative Ranks	12p	17.46	209.50
	Positive Ranks	20q	15.93	318.50
	Ties	27r		
	Total	59		
FunEnjoymentPostTest2.7Comics - FunEnjoymentPreTest2.7Comics	Negative Ranks	18s	19.28	347.00
	Positive Ranks	17t	16.65	283.00
	Ties	24u		
	Total	59		
FunEnjoymentPostTest2.8Comics - FunEnjoymentPreTest2.8Comics	Negative Ranks	13v	13.69	178.00
	Positive Ranks	14w	14.29	200.00
	Ties	32x		
	Total	59		
FunEnjoymentPostTest2.9Comics - FunEnjoymentPreTest2.9Comics	Negative Ranks	12y	21.42	257.00
	Positive Ranks	22z	15.36	338.00
	Ties	25aa		
	Total	59		
PersonalAbilityPostTest2.10Comics - PersonalAbilityPreTest2.10Comics	Negative Ranks	11ab	15.23	167.50
	Positive Ranks	22ac	17.89	393.50

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Ranks		N	Mean Rank	Sum of Ranks
	Ties	26ad		
	Total	59		
PersonalAbilityPostTest2.11Comics -	Negative Ranks	14ae	17.96	251.50
PersonalAbilityPreTest2.11Comics	Positive Ranks	22af	18.84	414.50
	Ties	23ag		
	Total	59		
PersonalAbilityPostTest2.12Comics -	Negative Ranks	17ah	18.79	319.50
PersonalAbilityPreTest2.12Comics	Positive Ranks	19ai	18.24	346.50
	Ties	23aj		
	Total	59		
FearOfUsePostTest2.13Comics -	Negative Ranks	19ak	15.05	286.00
FearOfUsePreTest2.13Comics	Positive Ranks	11al	16.27	179.00
	Ties	29am		
	Total	59		
FearOfUsePostTest2.14Comics -	Negative Ranks	25an	17.10	427.50
FearOfUsePreTest2.14Comics	Positive Ranks	9ao	18.61	167.50
	Ties	25ap		
	Total	59		
FearOfUsePostTest2.15 -	Negative Ranks	24aq	16.29	391.00

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Ranks		**N**	**Mean Rank**	**Sum of Ranks**
FearOfUsePreTest2.15Comics	Positive Ranks	10ar	20.40	204.00
	Ties	25as		
	Total	59		
IntentionToUsePostTest2.16Comics - IntentionToUsePreTest2.16Comics	Negative Ranks	20at	16.63	332.50
	Positive Ranks	18au	22.69	408.50
	Ties	21av		
	Total	59		
IntentionToUsePostTest2.17Comics - IntentionToUsePreTest2.17Comics	Negative Ranks	21aw	19.19	403.00
	Positive Ranks	17ax	19.88	338.00
	Ties	21ay		
	Total	59		
IntentionToUsePostTest2.17Comics - IntentionToUsePreTest2.18Comics	Negative Ranks	20az	21.85	437.00
	Positive Ranks	27ba	25.59	691.00
	Ties	12bb		
	Total	59		
IntentionToUsePostTest2.18Comics - IntentionToUsePreTest2.18Comics	Negative Ranks	17bc	21.59	367.00
	Positive Ranks	24bd	20.58	494.00
	Ties	18be		
	Total	59		

Appendix D

Combined and cross-loadings for cognition model

	Flow	PriorKnowledge	Usefulness	Clarity	Simplicity	Fear	SAM	SAC	Literacy	Representation	Confidence	PerAbility	Intent	Fun	Type	SE	P-value
Flow	0.878	0.312	-0.228	-0.221	0.170	0.211	0.188	-0.096	-0.237	0.180	0.024	-0.109	0.191	0.004	Reflect	0.095	<0.001
Flow	0.875	0.010	0.082	0.081	-0.189	-0.059	-0.126	0.287	0.064	0.120	0.084	-0.188	-0.135	0.170	Reflect	0.096	<0.001
Flow	0.699	-0.404	0.184	0.176	0.023	-0.191	-0.078	-0.239	0.217	-0.377	-0.135	0.373	-0.071	-0.217	Reflect	0.102	<0.001
PriorKnowledge	-0.231	0.732	-0.744	0.227	0.917	0.032	-0.208	0.463	-0.586	0.662	-0.059	-0.395	0.030	-0.115	Reflect	0.100	<0.001
PriorKnowledge	0.078	0.918	0.222	-0.084	-0.227	-0.122	0.059	-0.078	0.347	-0.282	0.074	-0.005	0.081	-0.003	Reflect	0.094	<0.001
PriorKnowledge	0.110	0.879	0.388	-0.102	-0.527	0.101	0.111	-0.305	0.126	-0.257	-0.028	0.334	-0.110	0.099	Reflect	0.095	<0.001
Usefulness	0.327	-0.178	0.895	0.168	-0.055	-0.019	-0.233	0.106	-0.028	0.059	-0.216	0.045	-0.008	0.129	Reflect	0.095	<0.001
Usefulness	-0.210	0.132	0.896	0.002	0.305	0.112	0.241	-0.068	-0.103	0.005	0.007	0.107	-0.054	-0.015	Reflect	0.095	<0.001
Clarity	0.056	-0.118	-0.408	0.690	0.541	0.151	0.076	-0.213	-0.309	0.417	-0.306	-0.039	0.252	0.178	Reflect	0.102	<0.001
Clarity	0.127	0.033	-0.370	0.621	0.394	0.063	-0.523	0.296	0.957	-0.617	0.196	-0.016	-0.338	-0.252	Reflect	0.104	<0.001
Clarity	-0.157	0.081	0.681	0.752	-0.824	-0.191	0.363	-0.049	-0.509	0.127	0.119	0.049	0.048	0.045	Reflect	0.100	<0.001
Simplicity	0.105	0.055	0.219	0.050	0.909	0.054	0.114	-0.092	0.038	-0.200	0.125	-0.019	-0.120	-0.120	Reflect	0.094	<0.001
Simplicity	0.022	-0.032	-0.083	0.073	0.930	-0.038	-0.249	0.023	0.426	-0.293	0.001	0.057	0.117	-0.052	Reflect	0.094	<0.001
Simplicity	-0.134	-0.023	-0.141	-0.131	0.865	-0.016	0.148	0.071	-0.498	0.525	-0.133	-0.042	0.001	0.182	Reflect	0.096	<0.001
Fear	0.143	-0.129	0.028	0.127	-0.073	0.856	-0.150	0.079	0.258	-0.159	-0.046	0.176	-0.262	0.203	Reflect	0.096	<0.001
Fear	-0.001	0.043	-0.002	-0.055	-0.026	0.944	0.064	-0.014	-0.005	0.017	0.002	-0.077	0.132	-0.064	Reflect	0.093	<0.001
Fear	-0.136	0.077	-0.025	-0.063	0.097	0.902	0.075	-0.060	-0.239	0.132	0.042	-0.087	0.111	-0.125	Reflect	0.095	<0.001
SAM	-0.450	0.104	-0.519	-0.131	0.261	0.037	0.875	0.327	-0.491	0.528	0.092	0.008	0.127	0.112	Reflect	0.096	<0.001

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	Flow	PriorKnowledge	Usefulness	Clarity	Simplicity	Fear	SAM	SAC	Literacy	Representation	Confidence	PersAbility	Intent	Fun	Type	SE	P-value
SAM	0.093	0.005	0.101	0.067	-0.042	-0.042	0.923	-0.053	-0.264	-0.007	-0.035	0.091	-0.051	-0.113	Reflect	0.094	<0.001
SAM	0.416	-0.129	0.487	0.071	-0.256	0.009	0.741	-0.320	0.907	-0.614	-0.065	-0.123	-0.086	0.008	Reflect	0.100	<0.001
SAC	-0.242	0.429	-0.133	-0.444	-0.151	0.263	-0.252	0.727	-0.845	1.093	-0.363	-0.018	0.151	0.544	Reflect	0.101	<0.001
SAC	0.011	-0.175	-0.523	0.026	0.928	0.059	-0.436	0.684	0.907	-0.932	0.572	-0.200	-0.078	-0.521	Reflect	0.102	<0.001
SAC	0.257	-0.294	0.695	0.467	-0.803	-0.355	0.737	0.654	-0.009	-0.240	-0.195	0.229	-0.087	-0.060	Reflect	0.103	<0.001
Literacy	-0.175	0.061	0.000	-0.086	0.039	-0.164	-0.083	0.119	0.898	0.289	0.203	-0.110	-0.004	0.158	Reflect	0.095	<0.001
Literacy	0.138	-0.098	-0.090	0.024	0.210	0.125	0.075	-0.017	0.937	0.067	-0.045	-0.157	-0.038	-0.132	Reflect	0.093	<0.001
Literacy	0.031	0.042	0.094	0.062	-0.258	0.034	0.005	-0.102	0.896	-0.361	-0.156	0.274	0.044	-0.021	Reflect	0.095	<0.001
Repres	0.228	0.105	0.276	0.072	-0.393	-0.177	-0.396	0.651	-0.864	0.698	-0.339	0.098	0.067	0.490	Reflect	0.102	<0.001
Repres	-0.118	0.027	-0.014	-0.012	0.265	0.082	0.091	-0.277	0.213	0.872	0.143	-0.229	0.119	-0.287	Reflect	0.096	<0.001
Repres	-0.064	-0.111	-0.207	-0.046	0.049	0.060	0.227	-0.245	0.479	0.871	0.128	0.151	-0.172	-0.105	Reflect	0.096	<0.001
Confid	-0.248	0.295	0.242	-0.430	-0.141	-0.096	0.270	-0.104	-0.637	0.564	0.816	-0.033	0.087	0.118	Reflect	0.098	<0.001
Confid	0.171	0.110	-0.440	-0.099	0.784	0.330	-0.239	0.221	0.526	-0.802	0.676	0.005	-0.272	-0.468	Reflect	0.103	<0.001
Confid	0.121	-0.443	0.140	0.587	-0.582	-0.203	-0.083	-0.091	0.231	0.115	0.712	0.033	0.158	0.309	Reflect	0.101	<0.001
PersAbility	-0.309	0.439	-0.221	-0.356	0.639	0.365	0.192	-0.060	-0.797	0.757	0.067	0.798	-0.118	-0.256	Reflect	0.098	<0.001
PersAbility	0.093	-0.178	0.046	0.168	-0.347	-0.170	0.003	0.034	0.237	-0.352	0.020	0.895	0.127	0.285	Reflect	0.095	<0.001
PersAbility	0.180	-0.210	0.149	0.147	-0.220	-0.153	-0.172	0.019	0.467	-0.319	-0.078	0.909	-0.021	-0.055	Reflect	0.094	<0.001
Intent	0.112	-0.036	0.104	-0.280	-0.230	-0.130	-0.043	0.311	-0.037	0.005	0.132	-0.424	0.813	0.107	Reflect	0.098	<0.001
Intent	-0.025	0.086	0.074	0.088	0.194	0.149	0.230	-0.200	-0.374	0.188	-0.115	0.265	0.873	-0.221	Reflect	0.096	<0.001
Intent	-0.079	-0.052	-0.169	0.171	0.020	-0.028	-0.188	-0.089	0.406	-0.192	-0.008	0.129	0.879	0.121	Reflect	0.095	<0.001
Fun	-0.034	-0.197	-0.420	0.134	0.513	-0.045	-0.201	0.223	-0.009	0.019	-0.030	-0.250	0.119	0.881	Reflect	0.095	<0.001
Fun	-0.161	0.117	-0.088	-0.071	-0.001	-0.019	0.128	0.033	-0.362	0.389	0.100	-0.048	-0.115	0.911	Reflect	0.094	<0.001
Fun	0.241	0.091	0.614	-0.073	-0.614	0.077	0.082	-0.308	0.460	-0.506	-0.088	0.360	-0.001	0.734	Reflect	0.100	<0.001

Appendix E

Combined and cross-loadings for motivation model

	flow	PriorK	pUseful	Repres	Simplicity	pFear	SAM	SAC	Literacy	pClarit	Confid	pAbilit	pIntent	pFun	Type	SE	P-value
Flow	0.878	0.312	-0.228	-0.221	0.170	0.211	0.188	-0.096	-0.237	0.180	0.024	-0.109	0.191	0.004	Reflect	0.095	<0.001
Flow	0.875	0.010	0.082	0.081	-0.189	-0.059	-0.126	0.287	0.064	0.120	0.084	-0.188	-0.135	0.170	Reflect	0.096	<0.001
Flow	0.699	-0.404	0.184	0.176	0.023	-0.191	-0.078	-0.239	0.217	-0.377	-0.135	0.373	-0.071	-0.217	Reflect	0.102	<0.001
PriorK	-0.231	0.732	-0.744	0.227	0.917	0.032	-0.208	0.463	-0.586	0.662	-0.059	-0.395	0.030	-0.115	Reflect	0.100	<0.001
PriorK	0.078	0.918	0.222	-0.084	-0.227	-0.122	0.059	-0.078	0.347	-0.282	0.074	-0.005	0.081	-0.003	Reflect	0.094	<0.001
PriorK	0.110	0.879	0.388	-0.102	-0.527	0.101	0.111	-0.305	0.126	-0.257	-0.028	0.334	-0.110	0.099	Reflect	0.095	<0.001
Usefuln	-0.127	0.050	0.822	-0.185	-0.272	-0.101	-0.009	-0.041	0.143	-0.070	0.227	-0.166	0.067	-0.125	Reflect	0.097	<0.001
Usefuln	0.327	-0.178	0.895	0.168	-0.055	-0.019	-0.233	0.106	-0.028	0.059	-0.216	0.045	-0.008	0.129	Reflect	0.095	<0.001
Usefuln	-0.210	0.132	0.896	0.002	0.305	0.112	0.241	-0.068	-0.103	0.005	0.007	0.107	-0.054	-0.015	Reflect	0.095	<0.001
Repres	0.056	-0.118	-0.408	0.690	0.541	0.151	0.076	-0.213	-0.309	0.417	-0.306	-0.039	0.252	0.178	Reflect	0.102	<0.001
Repres	0.127	0.033	-0.370	0.621	0.394	0.063	-0.523	0.296	0.957	-0.617	0.196	-0.016	-0.338	-0.252	Reflect	0.104	<0.001
Repres	-0.157	0.081	0.681	0.752	-0.824	-0.191	0.363	-0.049	-0.509	0.127	0.119	0.049	0.048	0.045	Reflect	0.100	<0.001
Simplic	0.105	0.055	0.219	0.050	0.909	0.054	0.114	-0.092	0.038	-0.200	0.125	-0.019	-0.120	-0.120	Reflect	0.094	<0.001
Simplic	0.022	-0.032	-0.083	0.073	0.930	-0.038	-0.249	0.023	0.426	-0.293	0.001	0.057	0.117	-0.052	Reflect	0.094	<0.001
Simplic	-0.134	-0.023	-0.141	-0.131	0.865	-0.016	0.148	0.071	-0.498	0.525	-0.133	-0.042	0.001	0.182	Reflect	0.096	<0.001
Fear	0.143	-0.129	0.028	0.127	-0.073	0.856	-0.150	0.079	0.258	-0.159	-0.046	0.176	-0.262	0.203	Reflect	0.096	<0.001
Fear	-0.001	0.043	-0.002	-0.055	-0.026	0.944	0.064	-0.014	-0.005	0.017	0.002	-0.077	0.132	-0.064	Reflect	0.093	<0.001
Fear	-0.136	0.077	-0.025	-0.063	0.097	0.902	0.075	-0.060	-0.239	0.132	0.042	-0.087	0.111	-0.125	Reflect	0.095	<0.001

continued . . .

. . . continued

	flow	PriorK	pUseful	Repres	Simplicity	pFear	SAM	SAC	Literacy	pClarit	Confid	pAbilit	pIntent	pFun	Type	SE	P-value
SAM	-0.450	0.104	-0.519	-0.131	0.261	0.037	0.875	0.327	-0.491	0.528	0.092	0.008	0.127	0.112	Reflect	0.096	<0.001
SAM	0.093	0.005	0.101	0.067	-0.042	-0.042	0.923	-0.053	-0.264	-0.007	-0.035	0.091	-0.051	-0.113	Reflect	0.094	<0.001
SAM	0.416	-0.129	0.487	0.071	-0.256	0.009	0.741	-0.320	0.907	-0.614	-0.065	-0.123	-0.086	0.008	Reflect	0.100	<0.001
SAC	-0.242	0.429	-0.133	-0.444	-0.151	0.263	-0.252	0.727	-0.845	1.093	-0.363	-0.018	0.151	0.544	Reflect	0.101	<0.001
SAC	0.011	-0.175	-0.523	0.026	0.928	0.059	-0.436	0.684	0.907	-0.932	0.572	-0.200	-0.078	-0.521	Reflect	0.102	<0.001
SAC	0.257	-0.294	0.695	0.467	-0.803	-0.355	0.737	0.654	-0.009	-0.240	-0.195	0.229	-0.087	-0.060	Reflect	0.103	<0.001
Literacy	-0.175	0.061	0.000	-0.086	0.039	-0.164	-0.083	0.119	0.898	0.289	0.203	-0.110	-0.004	0.158	Reflect	0.095	<0.001
Literacy	0.138	-0.098	-0.090	0.024	0.210	0.125	0.075	-0.017	0.937	0.067	-0.045	-0.157	-0.038	-0.132	Reflect	0.093	<0.001
Literacy	0.031	0.042	0.094	0.062	-0.258	0.034	0.005	-0.102	0.896	-0.361	-0.156	0.274	0.044	-0.021	Reflect	0.095	<0.001
Clarity	0.228	0.105	0.276	0.072	-0.393	-0.177	-0.396	0.651	-0.864	0.698	-0.339	0.098	0.067	0.490	Reflect	0.102	<0.001
Clarity	-0.118	0.027	-0.014	-0.012	0.265	0.082	0.091	-0.277	0.213	0.872	0.143	-0.229	0.119	-0.287	Reflect	0.096	<0.001
Clarity	-0.064	-0.111	-0.207	-0.046	0.049	0.060	0.227	-0.245	0.479	0.871	0.128	0.151	-0.172	-0.105	Reflect	0.096	<0.001
Confid	-0.248	0.295	0.242	-0.430	-0.141	-0.096	0.270	-0.104	-0.637	0.564	0.816	-0.033	0.087	0.118	Reflect	0.098	<0.001
Confid	0.171	0.110	-0.440	-0.099	0.784	0.330	-0.239	0.221	0.526	-0.802	0.676	0.005	-0.272	-0.468	Reflect	0.103	<0.001
Confid	0.121	-0.443	0.140	0.587	-0.582	-0.203	-0.083	-0.091	0.231	0.115	0.712	0.033	0.158	0.309	Reflect	0.101	<0.001
Ability	-0.309	0.439	-0.221	-0.356	0.639	0.365	0.192	-0.060	-0.797	0.757	0.067	0.798	-0.118	-0.256	Reflect	0.098	<0.001
Ability	0.093	-0.178	0.046	0.168	-0.347	-0.170	0.003	0.034	0.237	-0.352	0.020	0.895	0.127	0.285	Reflect	0.095	<0.001
Ability	0.180	-0.210	0.149	0.147	-0.220	-0.153	-0.172	0.019	0.467	-0.319	-0.078	0.909	-0.021	-0.055	Reflect	0.094	<0.001
Intenti	0.112	-0.036	0.104	-0.280	-0.230	-0.130	-0.043	0.311	-0.037	0.005	0.132	-0.424	0.813	0.107	Reflect	0.098	<0.001
Intenti	-0.025	0.086	0.074	0.088	0.194	0.149	0.230	-0.200	-0.374	0.188	-0.115	0.265	0.873	-0.221	Reflect	0.096	<0.001
Intenti	-0.079	-0.052	-0.169	0.171	0.020	-0.028	-0.188	-0.089	0.406	-0.192	-0.008	0.129	0.879	0.121	Reflect	0.095	<0.001
FunEnjo	-0.034	-0.197	-0.420	0.134	0.513	-0.045	-0.201	0.223	-0.009	0.019	-0.030	-0.250	0.119	0.881	Reflect	0.095	<0.001
FunEnjo	-0.161	0.117	-0.088	-0.071	-0.001	-0.019	0.128	0.033	-0.362	0.389	0.100	-0.048	-0.115	0.911	Reflect	0.094	<0.001
FunEnjo	0.241	0.091	0.614	-0.073	-0.614	0.077	0.082	-0.308	0.460	-0.506	-0.088	0.360	-0.001	0.734	Reflect	0.100	<0.001

Appendix F

Teacher voting upon milestones

TABLE F.1: Milestones in computer science history as voted for by teachers

Decade	School group	Milestone
1950s		
1951	One	Grace Hopper creates the first compiler
1951	Two	Eckert and Mauchly release UNIVAC /i, the first commercial electronic computer
1955	Six	MITs Whirlwind I becomes the first computer to display graphics on a video console
1957	Five	A team led by John Backus at IBM delivers a compiler for FORTRAN, the first high-level programming language
1960s		
1961	Two	A team led by MIT student Steve Russell creates Spacewar!, the first computer game (gaming)
1961	Three	A team led by MIT student Steve Russell creates Spacewar!, the first computer game (gaming)
1961	Six	UNIMATE, the first industrial robot, begins work at General Motors (robotics)
1963	Five	The first edition of ASCII (American Standard Code for Information Interchange) is published

Decade continued . . .

Decade ...continued

1968	Two	Donald Knuth publishes Volume 1 of "The Art of Computer Programming"
1968	One	The movie "2001: A Space Odyssey" introduces the world to HAL
1969	Two	The Apollo Guidance Computer plays a crucial role in steering Neil Armstrong and Buzz Aldrin to the lunar surface
1969	Three	UNIX is created and the C programming language begins development. This is by Ken Thompson and Dennis Ritchie
1970s		
1970	Five	E. F. Codd proposes the relational database management system (RDMS)
1970	Six	John Horton Conway invents the Game of Life cellular automaton; it is estimated that millions of dollars of computer time is used watching Lifeforms evolve
1971	One	Ray Tomlinson sends the first email message on ARPANET
1971	Two	IBM commercially releases the floppy disk
1977	Two	Steve Jobs and Steve Wozniak release the Apple II
1977	Three	Steve Jobs and Steve Wozniak release the Apple II
1980s		
1981	Six	Nintendo achieves its first video game success with Donkey Kong, designed by Shigeru Miyamoto (Gaming)
1982	Two	Sony and Phillips commercially release the compact disc
1985	Two	Windows is released
1985	Five	Windows is released
1988	Three	Robert Morris creates a computer worm that cripples the Internet (malware)

Decade continued ...

Decade ...continued

1988	One	Robert Morris creates a computer worm that cripples the Internet (malware)
1990 s		
1990	Two	Gang of Four Design Patterns were invented
1990	Three	At CERN in Geneva, Switzerland, Tim Berners-Lee creates the World Wide Web
1995	Two	Pixar releases Toy Story, the first feature film made entriely with computer-generated imagery (animation)
1995	Three	Pixar releases Toy Story, the first feature film made entirely with computer-generated imagery (animation)
1995	Six	Pixar releases Toy Story, the first feature film made entirely with computer-generated imagery (animation)
1996	One	Stanford graduate students Larry Page and Sergey Brin being developing Google
1996	Three	Stanford graduate Larry Page and Sergey Brin begin developing Google
1997	Two	NASA's Sojourner robotic rover moved semi-autonomously across the surface of Mars for eighty three days, sending spectacular images back to Earth
1997	Five	IBM's Deep Blue computer defeats human world champion Garry Kasparov
2000s		
2000	Three	The first major denial-of-service (DoS) attack is launched against CNN, Yahoo and eBay
2001	Two	In the wake of the 9/11 attacks, news websites continue running smoothly because of routing algorithms designed by Akamai Technologies

Decade continued ...

Decade ...continued

2001	Three	Bram Cohen develops BitTorrent, the controversial peer-to-peer file sharing protocol now estimated to account for 27-55% of all internet traffic
2005	Five	YouTube is launched, beginning a era of online video sharing
2007	Six	Apple releases the iPhone
2014	One	The neurogrid is invented by Kwabena Boahen (Stanford). Takes 40, 000 less power to run than a PC and mimics the human brain

Appendix G

Approval letters and consent forms

Government of **Western Australia**
Department of **Education**

Your ref :
Our ref : D15/0603447
Enquiries :

Ms Melanie Tarr
53 Merivale Way
GREENWOOD WA 6024

Dear Ms Tarr

Thank you for your application received 21September 2015 to conduct research on Department of Education sites.

The focus and outcomes of your research project, *The other art of computer programming: a visual alternative to communicate computational thinking* are of interest to the Department. I give permission for you to approach principals to invite their participation in the project as outlined in your application. It is a condition of approval, however, that upon conclusion the results of this study are forwarded to the Department at the email address below.

Consistent with Department policy, participation in your research project will be the decision of the schools invited to participate, individual staff members, the children in those schools and their parents. A copy of this letter must be provided to principals when requesting their participation in the research. Researchers are required to sign a confidential declaration and provide a current Working with Children Check upon arrival at Department of Education schools.

Responsibility for quality control of ethics and methodology of the proposed research resides with the institution supervising the research. The Department notes a copy of a letter confirming that you have received ethical approval of your research protocol from the Edith Cowan University Human Research Ethics Committee.

Any proposed changes to the research project will need to be submitted for Department approval prior to implementation.

Please contact Ms Bev Vickers, on 9264 4649 or researchandpolicy@education.wa.edu.au if you have further enquiries.

Very best wishes for the successful completion of your project.

Yours sincerely

ALAN DODSON
DIRECTOR
EVALUATION AND ACCOUNTABILITY

11 December 2015

151 Royal Street, East Perth Western Australia 6004

STREAM

System for Tracking Research Ethics Applications and Monitoring

APPLICATION FOR RESEARCH INVOLVING HUMAN PARTICIPANTS

SECTION 1 – PROJECT DETAILS

1.1 TITLE	
PROJECT NUMBER	11968
PROJECT NAME	The other art of computer programming: a visual alternative to communicate computational thinking
PROJECT SHORT NAME	a visual alternative to communicate computational thinking
PROJECT STATUS	Approved

1.2 DURATION				
WHOLE PROJECT	**FROM:**	28 July 2014	**TO:**	30 November 2017
DATA COLLECTION PHASE	**FROM:**	1 October 2015	**TO:**	30 November 2017

1.3 APPLICATION TYPE		
MULTICENTRE PROJECT	***PERMITS/LICENCES REQUIRED***	***EXECUTIVE APPROVAL***
☐	☒	☐

1.5 STUDENT PROJECT	
Is this project for the purposes of a degree (student project)?	Yes

STUDENT NUMBER	***SCHOOL***	***DEGREE TYPE***
955003		PhD or Doctorate

Information letter to principals

Research Project: The other art of computer programming

Dear [insert principals name here],

My name is Melanie Tarr and I am a PhD candidate with Edith Cowan University. My area of research is visual communication and the 12 year old child. I am seeking to understand motivation and learning computer programming through visual communication. This is to encourage more children into studying the discipline of programming. I am seeking your consent to involve your school in this project because it is representative of a range of schools found in WA and offers generalisability of findings.

My research project involves examining Year 8 students' visual learning and the impact of pictures on cognition and motivation via a lesson on computational thinking with 6 survey questions before and 13 after as well as five within. There is also an optional audio recorded focus group for students to participate in at a later date. This lesson, which will take 40 minutes of class time, will be administered by me in February 2016 through electronic surveys. It will allow me to understand the impacts of learning programming through visual communication upon the Year 8 students. The development of the lesson topics will be online at a wiki should teachers wish to view it and contribute to it. The time commitment for teachers to the wiki will range between nothing and whatever amount of time the teacher determines. The student participant surveys will be collected via the Internet for data analysis purposes only.

I am seeking your permission to approach your computing staff to recruit Year 8 students to participate in the project. Both students and teachers will be fully informed as to the nature of the research, and I will seek written parental consent for students taking the lesson and focus group interview. The 10 minute audio recorded focus group interview will consist of a smaller group of Year 8s wishing to give their time for this. The purpose of the focus groups is to collect feedback from students about: the lessons; the impact on their interest in learning about computational thinking or computer science in future; and their views about learning through the use of comic style visual instruction.

I am aware of the perceived extra burden that involvement may seem to place on the teaching staff. However, all testing will be undertaken via internet delivery by me as the researcher at times that are convenient to the teaching staff, and cause minimum, if any disruption. The teacher's commitment to participation is optional and at their own discretion. The teachers will need to distribute information letters and collect consent forms. They will also need to provide an activity for those students who do not provide consent for the research project. This will be during the 40 minute lesson the student participants undertake. The total time required from the teaching staff will be the 40 minute lesson plus any additional optional contribution they perform as teacher participants to the wiki.

All data collected will only be used for the purposes of this research and not disclosed to other parties. Staff and student responses will be anonymous and confidential: the school, teachers, or students will not be named or identified in any way in the final report. Participation is voluntary and your staff and students may withdraw from the project at any stage prior to data collection, without explanation or penalty.

This project has ethics approval from Edith Cowan University, Human Research Ethics Committee, approval number - 11968.

If you have any concerns or complaints about the research project and wish to talk to an independent person, you may contact: Research Ethics Officer
Edith Cowan University
270 Joondalup Drive
JOONDALUP WA 6027
Phone: (08) 6304 2170
Email: research.ethics@ecu.edu.au

The project has also met the policy requirements of the Department of Education and I have a current/valid working with children check as evidenced by attached documentation. In accordance with Department policy, a summary of the findings will be made available to you at the completion of the project and a copy of the final PhD report can be made available to you upon request.

The aim of the project is to produce a report that will hopefully shed light on the formation and development of attitudes on visual literacy and inform teaching practice. I hope you will consent to allow your school's involvement with the project, and look forward to your response. For further information, I can be contacted on 0423329518.

Melanie Tarr
Primary Researcher – The other art of computer programming
PhD Candidate
School of Communications and Arts
Faculty of Education and Arts
Edith Cowan University
Phone: 0423329518
Email: mknights@our.ecu.edu.au

Principal Supervisor – Dr Stuart Medley
School of Communications and Arts
Faculty of Education and Arts

Edith Cowan University
Phone: 0423329518
Email: s.medley@ecu.edu.au

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