The synthesis of a unified pedagogy for the design and evaluation of e-learning software for high-school computing.

Vol 1 of 3 - Thesis

by

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ABSTRACT

In recent decades, several countries[1] have applied a resurgent focus to high-school computer science in the hope that it will provide the foundations for strong and innovative national IT sectors. The UK is one example undertaking this transition, and experiencing the associated challenges placed on the teaching community. In parallel, recent years have seen a trend towards enriching education with digital resources, specifically e-learning software. This study offers a practical contribution to the computer science teaching community by supporting the provision of e-learning software, and hence the increased use of e-learning in high-school teaching. However, it recognises that there remains a concern over the inconsistent pedagogical quality of many e-learning implementations. To safeguard the pedagogical quality of e-learning software, this study offers a research contribution by defining: **(1)** a comprehensive set of pedagogical heuristics to inform the design of e-learning software; **(2)** an associated e-learning evaluation protocol to guide the evaluation and selection of e-learning software for use in schools; and in doing so, **(3)** contributes to the under-researched area of high-school computing pedagogy. The proposed pedagogy synthesises a vast body of knowledge on learning theories into a comprehensive, yet accessible, set of heuristics. These heuristics supplement existing literature by focusing more tightly and in depth on pedagogy, rather than usability. The pedagogy synthesises the following learning theories: constructivism, social constructivism, connectivism, and cognitive load, and additionally gives pedagogical focus to VARK learning styles, ARCS[2] motivational design, collaborative learning, gamification, and computational thinking. The e-learning evaluation protocol builds upon existing best practice in evaluation procedures but is unique in its characteristics and focus. The study follows a rigorous three phase mixed methods exploratory design in which the e-learning pedagogy and evaluation protocol were explored and iteratively developed in concert with input and evaluation from education experts and teachers. In parallel, practice-based input was secured via student usage of prototype e-learning software designed in adherence to the pedagogy. The findings of this research offer preliminary validation of the appropriateness and comprehensiveness of the e-learning pedagogy, and the final phase demonstrates statistically significant learning increases based on student usage of the e-learning software prototype. Additionally, this research offers preliminary validation of the reliability and validity of the evaluation protocol. Building on the findings of this research, several possibilities are outlined to further empirically establish this research, or develop it further into new avenues.

[1] Such countries include, but are not limited to Australia, Belgium, France, India, Israel, Italy, New Zealand, Sweden, South Africa, Russia, the United Kingdom, and the United States.

[2] ARCS acronym stands for Attention, Relevance, Confidence and Satisfaction.

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NOTE ON NAVIGATION

The digital version of this document contains internal navigation:

1. Figures and Tables are cross-referenced using standard practice, standard font and link accordingly.
2. The Table of Contents, List of Tables, and List of Illustrative Material are provided using standard practice, and link accordingly.
3. References to the Appendices within the body of the thesis do not link to the Appendices documents, they are for reference only.
4. The heuristics are cross-referenced and link accordingly, using the heuristic number (**only**) and standard font.
5. A Glossary of Terms is provided for terminology that may potentially be uncommon. The first genuine use of the term is marked as a hyperlink (blue underline) and provides a link back to the term in the glossary. Subsequent use of the term is treated as normal.

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GLOSSARY OF TERMS

Glossary Term	Description
Accommodation	In relation to constructivist principles, accommodation is the process by which existing schemas must be altered to cope with new experiences that contradict the existing mental model.
Active Processing	According to cognitive load theory, human learning occurs when the appropriate cognitive processes are engaged to mentally organise incoming auditory and visual sensory information and integrate it with existing knowledge so that it can be stored in, and recalled from, long term memory.
Assimilation	In relation to constructivist principles, assimilation is the process by which new information reinforces an existing schema, and the schema is augmented with new information.
Behaviourism	Behaviourism is a systematic approach to the understanding of human or animal behaviour; it assumes that behaviour is a consequence of individual history. Behaviourism gives specific focus to positive reinforcement and punishment, together with the individual's current motivational state and controlling stimuli.
Collaboration	Collaboration involves a joint group endeavour to solve a problem; all group members contributing to the same task.
Collaborative Learning Environment (CLE)	A collaborative learning environment is a software system that offers various tools and services that support learners in working and learning together.
Cognitive Load Theory (CLT)	CLT explains how incoming information from eyes and ears is transformed into knowledge and skills in human memory. It proposes that learners do not passively receive incoming information, but instead undertake active cognitive processes that organise the incoming information into logical structures and integrate it with existing knowledge for long term recall.
Constructivism	Constructivist approaches recognise a real-world that sets limits on our experiences, but proposes that there is no uniformly perceived single reality; in fact, each person's perception of reality is a mental construct founded on interpretation of their interactions with the world. An individual's reality is therefore based on their existing

Glossary Term	Description
	experience and understanding, which is in turn used to make sense of their current perception of events.
Cooperation	Cooperation involves the division and assignment of tasks within the group to solve the problem.
Deep Learning	As opposed to surface learning, in which learning material is passively memorised with a primary aim of passing assessments; deep learning is learning where there is a vigorous interaction with the learning material to truly understand it and integrate it with previous experience and knowledge. Meaning it is integrated into existing mental schemas in the learner's long-term memory.
Dual Channels	Humans have separate channels for processing visual and auditory material.
Equilibrium	In relation to constructivist principles, equilibrium is the process of arriving at a stable state where there is no longer conflict between new knowledge and existing mental schemas.
Extrinsic	Not forming part of or belonging to a thing, or originating from the outside. Typically, something originating outside of a thing and acting upon that thing (Merriam-Webster 2018a).
Far Transfer	Far transfer is the application of skills and knowledge learned in one situation to a different situation. It builds upon deep learning and requires learners to adjust the underlying principles they have learnt for use in a new scenario or new problem.
Gamification	Gamification is the use of game design elements in non-game contexts. It does not focus on creating fully-fledged games, but instead uses game dynamics, mechanics, and frameworks to increase pleasure, fun, motivation, and influence behaviour.
Generation Y	Generation Y refers to the specific generation born between the 1980s and 2000; this term was given to this generation since they succeed Generation X. They are defined by several characteristics, one of the most notable being that they were born and raised in an emerging world of technology, arguably making them inherently knowledgeable of digital technologies.
Heuristic	A heuristic is a specific rule-of-thumb or argument derived from experience

Glossary Term	Description
Higher Order Thinking	Higher order thinking theorises that some types of learning are more valuable but require more cognitive processing and are more difficult to teach and learn. According to Bloom's taxonomy analysis, evaluation and synthesis are thought to be of a higher order as compared to remembering, understanding and applying facts and concepts.
Intrinsic	Belonging to the essential nature or constitution of a thing or originating and included wholly within an organ or part (Merriam-Webster 2018c).
Key Stage	State schools in England, Wales, Northern Ireland and the British Territory of Gibraltar adhere to targets set by the National Curriculum. The National Curriculum is divided into key stages according to pupil age and the school years the key stage is planned to be taught in.
Mental Model	Mental models are our internal symbolic representation of external reality. They explain our thought process about how something works in the real-world, and shape our behaviour and approaches to solving problems.
Metacognition	Metacognition is *"cognition about cognition"*; in this context, it relates to thinking about one's own thinking process such as study skills, memory capabilities, and the ability to monitor learning. It is a self-awareness of our own cognitive processes and the understanding of how to regulate those processes to maximise learning.
Mindful Activity	Mindful activity is activity in which the learner is in direct contact with real or virtual objects, and is encouraged to manipulate them to think, hypothesise and test their hypothesis.
Multi-Modal	Multi-modal approaches combine a mixture of approaches and teaching methods to offer balanced modal coverage.
Learning Theory	Learning theories are conceptual frameworks that describe how humans acquire new, or modify or reinforce existing knowledge, behaviour, skills, values, or preferences.
Limited Mental Capacity	At any given time, humans can actively process only limited information in each channel; material that exceeds this threshold may enter working memory but will not be processed and encoded into long term memory.

Glossary Term	Description
Orienting Reflex	Orienting Reflex is an organism's immediate response to a change in its environment; that change is not sudden enough to elicit the startle reflex, but is a novel or significant stimulus. This initial response makes the organism temporarily more sensitive to the stimulation.
Part-task Instruction	Traditional teaching methods take a part-task approach which breaks the syllabus down into small parts that teach topics and sub-topics; these are, in turn, followed by frequent (relatively small) practice activities. This approach gradually builds knowledge and skills in the learner.
Pedagogy	Pedagogy focuses on the theory and practice of education, more specifically the study and practice of how best to teach and assess.
Problem Manipulation Environment (PME)	As part of active learning, students are encouraged to engage in mindful activity. A PME supports such activity and should have a low floor in terms of ease of entry and a high ceiling in terms of features and functionality that learners can eventually master. In a computing context, such an environment should allow students to model and run simulations, look-under-the-hood on existing solutions, employ trial and error, implement designs, and test and debug solutions.
Progressive Disclosure	Progressive disclosure is an instructional technique used to reduce cognitive load by disclosing the minimal learning material required and releasing more information progressively, thereby avoiding learners being overwhelmed. This technique can also be used to create curiosity and maintain suspense by not providing all the necessary material in one go.
Reflective Practice	Reflective practice is the capacity to reflect (think deeply or carefully) on our actions or thought processes to develop insight that, in turn, enables improvement. It is argued that experience alone does not necessarily lead to learning; deliberate reflection on experience is essential.
Schema	Schemas are the mental constructs that organise and categorise our skills, and knowledge and understanding of the world.
Sensation-seeking Reflex	Sensation seeking is a personality trait with a biological basis defined by the *"seeking of varied, novel, complex, and intense sensations and*

Glossary Term	Description
	experiences, and the willingness to take physical, social, legal, and financial risks for the sake of such experience" (Zuckerman 1994, p.27).

1 INTRODUCTION

Digital technology penetrates all aspects of our lives and is fundamentally interwoven in the fabric of society in developed countries. It is no longer a '*nice to have*', it is a necessity; a lack of access and knowledge in using digital technology leaves those without at a disadvantage economically, personally, and in terms of future opportunities. This is true at both an individual level and at a national level, as nations compete within the global economy.

The rapid innovation brought about by digital technology is driving globalisation and is a major competitive factor between countries. So much so that nations compete on the strength of their information technology (IT) sectors. Closely following the national imperative to invest in their IT sector is the recognition that at the heart of a country's IT sector is a well-educated and skilled workforce; yet these skills are in global short supply.

The UK is one country actively engaged in this global competition. Around the turn of the last decade (2010), although the UK's IT sector was in good standing, there were deep concerns regards its inability to meet the demand for IT professionals, affecting the economy and global competitiveness. This in turn led to several high-profile critiques of UK computing education, which led to a well-publicised body of inquiry and political bombast that UK computing education (especially in high-schools) was in crisis.

Significant reform was introduced to the computing curriculum in schools, and the information and communications technology (ICT) curriculum was disapplied in 2012[3] and replaced with a renewed focus on computing and computer science. This reform created considerable impact on the UK's high-school teaching community. In the context of this research, the most important being:

1. A shortage of qualified specialist teachers,
2. A lack of Continued Professional Development (CPD) and subject-specific pedagogy, and
3. A concern over often inadequate technical teaching resources, of which e-learning software is included.

In parallel to these events, a natural by-product of the ubiquitous nature of technology is that it also permeated into education; recent decades have seen a growing movement towards technology-enhanced learning. There has been rapid growth of e-learning usage in industry, and to a good extent in schools. Therefore, in view of the challenges faced in computing education in schools, one approach to support teachers and high-school computing is the increased usage of e-learning software to supplement instruction and aid individual learning.

[3] Meaning ICT remained a national curriculum subject at all four key stages until the new national curriculum came into force in September 2014. However, the legal requirement for schools to adhere to the specific national curriculum programmes of study, attainment targets and statutory assessment arrangements was removed.

In the context of this research, e-learning software is considered: software that delivers content and instructional methods to facilitate learning, ideally in an engaging and interactive manner that promotes active learning. The e-learning software should cover a complete topic or portion of the curriculum (e.g. algorithms, programming, data representation, networks, etc.).

Several learning benefits are reported from the use of e-learning software, in terms of learning performance and motivation. However, at the foundation of this research is the recognition that there remains inconsistency in the quality of existing software; typically, in the areas of pedagogical design and alignment with educational needs.

1.1 Research Aims

Considering the aforementioned context this research aims to support the increased use of e-learning software in high-school computer science, and to simultaneously safeguard the pedagogical quality of the software. It does this by defining a comprehensive set of pedagogical heuristics for use by teachers or other educators in the design, or evaluation and selection, of e-learning software for high-school computing. The heuristics can also be used by instructional designers engaged in the design of computing e-learning software.

1.2 Research Contributions

The objective of this study is to synthesise a wide body of disparate learning theory knowledge into a holistic pedagogy for e-learning that concentrates on high-school computing. In addition, the pedagogy must communicate the essence of this wide body of pedagogical knowledge in a detailed, yet understandable and accessible form, to a (primarily) teacher audience.

Building on the e-learning pedagogy is an e-learning evaluation protocol that offers structure and guidance to teachers or other educators in the evaluation and selection of e-learning software for use in their teaching.

1.3 Research Question and Hypotheses

This study seeks to answer, *'whether there are improved student assessment results from e-learning software that is designed in adherence with the pedagogical heuristics developed in the study'*. This leads to the following experiment hypothesis, which is answered in the final phase:

1. H_0: The use of e-learning software designed in adherence to the pedagogical heuristics presents no difference in student learning performance.
2. H_1: The use of e-learning software designed in adherence to the pedagogical heuristics presents improved student learning performance.

1.4 Research Context

The recent events and challenges in the UK serve as a backdrop for this research, and motivate this study's support for computing education and computer science teachers through the difficult transition from ICT to computer science. However, the UK is by no means unique; the transition of high-school curriculums to a more computer science focus has been undertaken by several countries, with varying results and a cross section of similar challenges. This gives a clear indication of the transferability of this study in an international context.

1.5 Challenges and Limitations

It should be remarked that research in a school context, with in-service teachers and school pupils, was the defining challenge of this research. Much of the research had to be scheduled within the school academic year avoiding busy periods, exam periods and holidays, and trying to fit into the general availability of both the teachers and students. In particular in the final phase, the study had to be scheduled according to the GCSE scheme of work, or risk being delayed to the following year.

The grooming and preparation of schools and their teachers to participate took many months, typically starting in the previous academic year and on numerous occasions leading to teachers withdrawing at the last minute due to their pre-existing school workload. Hence throughout the study it was a constant challenge to secure teachers and students to participate.

Section 3.4.2.1 discusses in detail the relative limitations in transferability of the student sample in the qualitative exploratory phases. Additionally, it should be noted that as is common in computing there was a significant gender imbalance (only one female student was involved in the exploratory phases). With reference to section 3.6.2.2 the gender imbalance remained in the final quantitative phase but was broadly aligned with the overall GCSE computing population.

As discussed in section 8.2, this research does not propose e-learning as a replacement for high-school teachers. Hence by design, it does not consider a control group by which students are taught by traditional didactic methods vs e-learning software designed in adherence with the pedagogy. An alternate control group was considered with students using a different e-learning software which is purportedly equivalent to the e-learning software prototype. However, in consideration of the quantitative priority in Phase 3 and a student sample of 66, this was rejected in favour of safeguarding statistically significant results and confirming improved learning performance based on the e-learning prototype. The use of alternate control groups is further discussed as future work in section 8.2.

Although not a challenge or limitation per se, the ethical implications of the research work were addressed under the UCLan ethical approval process, by the Science, Technology, Engineering, Medicine and Health (STEMH) ethics committee. The three-phase research methodology secured separate ethics approval for each phase, and the inclusion of underage participants was managed and approved with due consideration. Although not limited to these areas, special consideration was given to: how information was given to schools (head teacher), teachers, parents and students to secure their informed consent; how withdrawals were managed; the appropriateness of research protocols, instruments and materials for the underage student participants; how participant information was anonymized; and how research data was stored, protected and archived.

1.6 Thesis Organisation

This thesis is presented in three volumes; the thesis body (volume 1) and the appendices (volumes 2 and 3). The next chapter presents the academic foundation of the study (literature review), giving focus to: the underlying problem domain and international context; the research shortfall this study addresses - in terms of e-learning heuristics, evaluation protocols, and pedagogy for high-school computing; the current status and concerns relating to e-learning software; and the learning theories underpinning the pedagogy.

Later chapters elaborate in detail on the: three phase mixed methods research design; the synthesis of the e-learning pedagogy; the synthesis of the e-learning evaluation protocol; the results from all three phases of the study; the discussion and interpretation of those results; and the conclusion, contribution and future works springing from this study.

2 LITERATURE REVIEW

2.1 Digital Technology and the Economy

In 2012, the UK seemed to be in good standing with a global ICT Development Index (IDI)[4] position of 8th (ITU 2013). However, in the 2011 MacTaggart lecture, Eric Schmidt (Google Chief Executive) lamented the UK's failure to build upon its long history in innovation. He expressed the opinion that the UK needed to start at the very beginning with education, and to reignite children's passion for science. This was echoed by the 2012 figures from e-skills UK which showed that, from 2002 to 2010, while applicants for higher education (HE) courses increased by 51%, applicants for single subject IT-related courses decreased by 28% (e-skills, 2012). At the time, this led to a well-publicised body of inquiry, consisting of various reports, analyses and a good measure of political rhetoric, that asserted that computing education in the UK was in crisis. This section explores the economic portion of that body of enquiry, contrasting it with current digital drivers and indicators in the UK and globally.

2.1.1 Digital Technology is Ubiquitous

The prevalence and ubiquitous nature of Information and Communication Technology (ICT) in developed countries and its impact on recent generations is well documented (DCMS & DBIS 2009; Halse et al. 2009; Dutta & Mia 2011; Baller et al. 2016).

"Few today would go back willingly to a world without the Internet and its many associated developments. For many young adults, conceiving of such a world may even be impossible. ICT, and the internet particularly have already changed the world dramatically, and all indications point to an even higher rate of transformation of our lives over the next decade." - (Dutta & Mia 2011, p.29) World Economic Forum.

Five years later, in 2016, the World Economic Forum was heralding the "… *Fourth Industrial Revolution. Processing and storage capacities are rising exponentially, and knowledge is becoming accessible to more people than ever before in human history.*"(2016, p.v).

One quantifiable metric of global technology dependency is worldwide internet usage. As reported by the International Telecommunications Union (ITU 2014; ITU 2017a) and the UK Office of National Statistics (2013; Prescot 2017) internet penetration continues to grow in both developing and developed countries, and the UK is ahead of most developed countries (refer to Table 1).

Whilst internet access varies depending on household composition, it is important to note that 98% of UK households with children had an internet connection in 2017 (Prescot 2017). Also there is a growing trend,

[4] The ITU Development Index (IDI) is a benchmark of ICT development in 176 economies; it measures 11 indices that are subdivided into three categories: access; use; and skills.

both globally and in the UK, of accessing the internet *'on the go'* via mobile devices; in 2017 73% of UK adults accessed the internet from a mobile device (Prescot 2017).

	Internet Penetration (Households)		
	Developing	**Developed**	**UK**
2014	32%	78%	83%
2017	42.9%	84.4%	90%

Table 1: Comparison of global internet penetration and the UK

Adapted from (Office of National Statistics 2013; ITU 2014; Prescot 2017; ITU 2017a)

As early as 2009, the Digital Britain Report (DCMS & DBIS 2009) from the Department for Business Innovation and Skills (BIS) and the Department for Culture, Media and Sport (DCMS) gave a realistic representation of how technology underpins the UK in areas such as: personal, business and mass media communications; personal and commercial transport; energy and utility infrastructure; the financial industry; high street credit/debit card transactions; online purchases; digital living based on new digital services; new ways of working (telecommuting); digital and self-publishing; education; healthcare; online banking, job searches and recruitment; and e-government. These areas remain relevant and have all intensified; more recently the ITU reflects a more holistic perspective of an ICT ecosystem in which the Internet of Things (IoT), cloud computing, big data, and artificial intelligence are tied to every aspect of our lives (ITU 2017b). Refer to Figure 1.

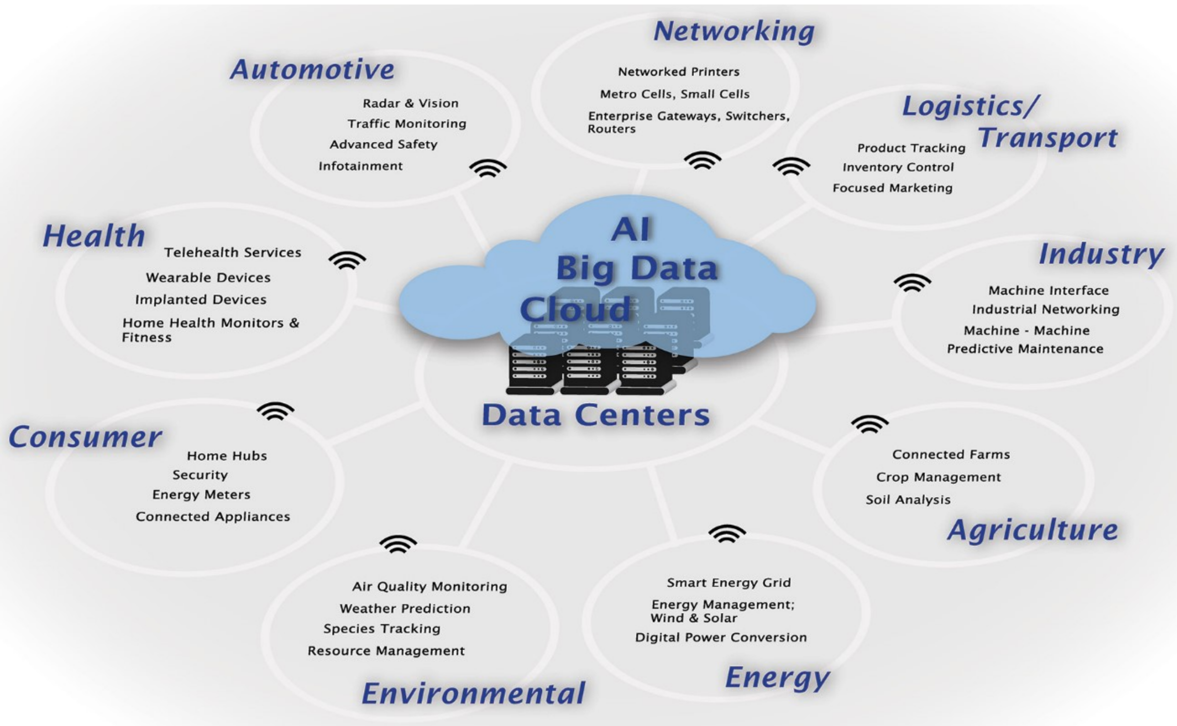

Figure 1: IoT, cloud computing, big data and artificial intelligence - the new drivers of the ICT ecosystem

Source: (ITU 2017b, p.95)

2.1.2 The Economic Benefit to the UK

At the turn of this decade (2010), the magnitude of the positive impact that digital technology had on the UK economy was quantified in various metrics:

- IT and digital communication sectors accounted for nearly £1 in every £10 that the whole economy produced each year (DCMS & DBIS 2009);
- The IT & telecoms industry accounted for 8% (£75 billion) of the UK's total Gross Value Added (GVA). (e-skills UK 2012);
- The economic contribution of the internet in 2009 was worth an estimated £100 billion to the UK economy (Boston Consulting Group 2010, p.5).

Although the impact that digital technology has on the UK economy has increased, more recent reporting does not give such a clear-cut snapshot. In 2017, the Office of National Statistics reported that 77% of UK adults bought goods or services online, an increase from 53% in 2008. Furthermore, in 2017, 93% of adults who had bought online in the last 12 months had done so from UK online vendors.

As reported by the World Economic Forum (Baller et al. 2016), the estimated value of globalisation in 2016 was US$73.5 trillion. This is apportioned to the nations participating in the global economy, of which the UK is a major contributor, and an estimated 75% of those benefits are captured by companies in traditional industries.

2.1.3 The Digital Divide

Although digital technology is argued to be ubiquitous, it is only ubiquitous for those that have access and the skills to use it. The digital divide exists on a global level between countries, and on a national level within the populations of each country. In 2017, the ITU (2017a; 2017b) continued to report on the global digital divide; the proportion of households with Internet access was reported to be 84.4% for developed countries, 42.9% for developing countries, and only 14.7% for the least developed countries. Furthermore, on a 10-point scale, the gap between the lowest and highest performing countries in the ITU index, grew to 8.02 points. Most importantly, the ITU reported that there was a strong correlation between a country's economic and ICT development, which seemed to be a self-sustaining phenomenon.

In the UK, PricewaterhouseCoopers (PwC) (2009) estimated the total potential economic benefit from getting everyone in the UK online as being in excess of £22 billion. Later, in 2015, the Tinder Foundation (Oliver Hogan, Colm Sheehy 2015, p.4) cite a yearly benefit of £358 million for individuals, and £243 million for the government in additional revenue. Furthermore, taking a 10-year view up to 2025 they estimated an NPV[5] of £14.3 billion for the investment of equipping the nation with basic digital skills.

[5] Net Present Value

2.1.4 Globalisation and National Competitiveness

Building on the discussion of the digital divide, globalisation has introduced fierce competition, and led to the situation where the strength of a country's IT sector is critical to its global economic survival. Decisions relating to policy and investment in digital technology are now identified as being of national importance. At the start of this decade, the Royal Academy (2009) and Oxford Economics (2011) raised alarm bells that the global shifting of skills and workforce was leading to investment wherever the IT skills were strongest, and that countries with inadequate skills would not be able to compete. At that time, e-skills UK (2012) was also reporting that firms in emerging economies were investing aggressively in digital technology, and the number of firms increasing their investment by over 20% was twice as high compared to Europe.

In fact, in 2012 the UK was rated highly with respect to IT investment and utilisation, and was actually in a relatively strong position globally. However, the overriding stance from the government and semi-governmental agencies was that there was no room for complacency, and that the UK must work even harder to reach the levels of its Nordic neighbours.

Since then, the UK policy stance has proven to be justified by the findings of the World Economic Forum and the ITU. In 2016, the World Economic Forum (Baller et al. 2016) reported that firms would face increasing pressure to innovate continuously. Additionally, the report parallels the growth of globalisation with the development of the commercial internet and quantifies the growth of globalisation since 1980 from US$11.1 trillion to US$73.5 trillion.

The ITU (2017b) report that the UK was one of six European countries in the top ten IDI rankings. This was attributed to *"high levels of ICT development as a result of high levels of investment in ICT infrastructure, high-quality networks, and high levels of take-up of services by consumers"* (ITU 2017b, p.35). It was noted that these countries also stand towards the top of the rankings for gross national income (GNI) per capita and other economic indicators.

On the surface, the UK's lack of complacency has paid dividends both economically and in terms of their global ICT rankings: the World Economic Forum ranked the UK 15th in their Networked Readiness Index[6] (NRI) in 2011 (Dutta & Mia 2011), and 8th in 2016 (Baller et al. 2016); whilst the ITU ranked the UK 8th in 2012 (ITU 2013), and 5th in 2017 (ITU 2017b).

However, the UK's lack of complacency must continue since the World Economic Forum reports relatively poor rankings in terms of affordability and with significance to this research: **skills** (refer to Figure 2).

[6] The Networked Readiness Index is reported by the World Economic Forum. It assesses the networked readiness of 139 economies across 53 individual indicators that are subdivided into four categories: environment; readiness; usage; and impact.

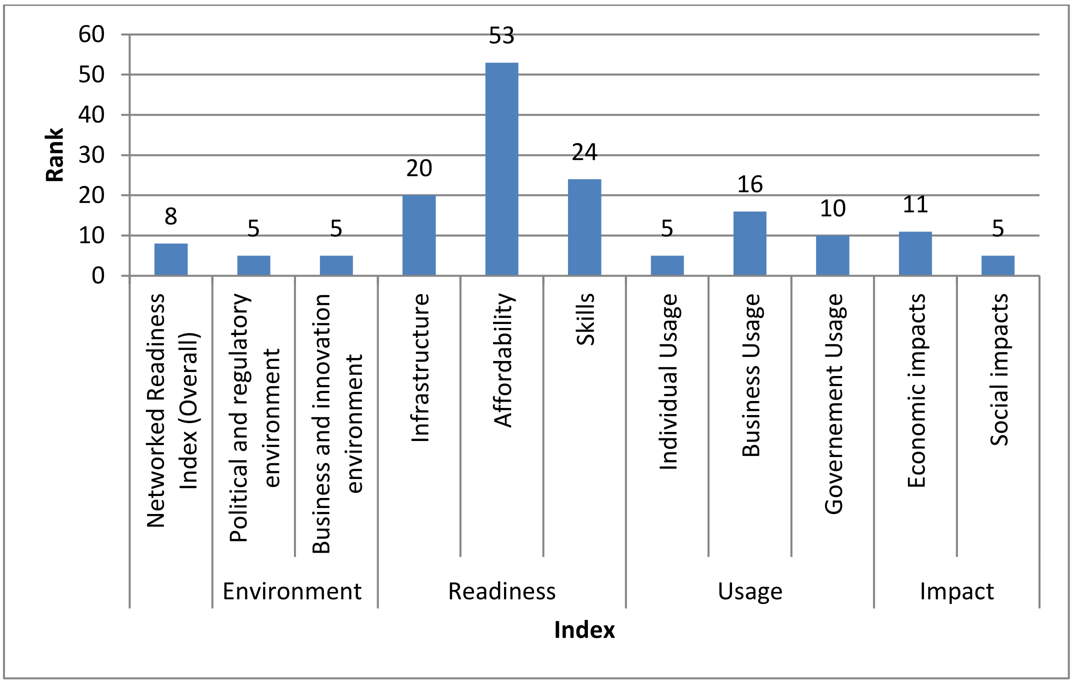

Figure 2: UK overall and sub-index rankings for Networked Readiness Index 2016

Adapted from (Baller et al. 2016)

2.1.5 Demand for IT Professionals

It is well established that a skilled workforce is at the heart of any country's IT Sector, that those skills are globally in short supply, and that the skills shortage will intensify in the foreseeable future (Thomas et al. 2007, p.14). For the UK to continue to enjoy the aforementioned economic benefits and remain competitive in the global economy, it must continue to focus on resolving the skills gap. In 2012, set against a backdrop of increasing demand for IT professionals versus the drop in higher education IT applicants, this was an area of concern. E-skills UK (2012) quantified this demand in terms of job vacancies; in 2011, there were approximately 116,000 advertised vacancies for technology (IT & Telecoms) professionals during each of the four quarters as compared with 82,000 during the whole of 2009. Furthermore, predicted growth rates up to 2020 showed the IT professional workforce was expected to grow at 1.62% per annum, nearly double the predicted growth rate for UK workers overall. These findings were substantiated by a Confederation of British Industry (CBI) survey which showed that businesses continued to report a shortage of people with science, technology, engineering and maths (STEM) skills (CBI 2011). Furthermore, among science, engineering and IT firms, more than 84% viewed the number and quality of STEM graduates as a priority concern (CBI 2011).

In recent years, despite a significant government focus and a shakeup within the high-school computer science curriculum, a turnaround in the UK digital skills shortage has not occurred. The Tech Partnership, the successor to e-Skills UK, reports that on average, 163,000 vacancies for digital specialists were advertised across the UK during each quarter of 2015; this was an increase on the 2011 figure of 116,000 per quarter (TechPartnership 2016). Using the latest workforce estimates from the Office of National

Statistics in conjunction with internal forecasts developed in association with Experian, the Tech Partnership (2016, p.1), also reported that:

- 1.8m (6%) of the UK workforce were working in the technology sector – 1.3m (74%) as technology specialists;
- Between 2015 and 2025 the number of people working as technology specialists was forecast to increase by approximately 28% (2.8% per annum), to 1.65m people;
- By comparison, in the same period, the UK workforce was expected to grow only by around 7%.

The Tech Partnership (2016) forecasted that total demand, including growth and replacement of industry-leavers, was estimated to be 1.71m gross job opportunities between 2015 and 2025. Considering the high educational demands of the industry, a significant portion would need to be filled by those graduating through education. However, analysis by the Tech Partnership (2015) of data from the Higher Education Statistics Agency (HESA) for the period 2013/14 showed that of 777,600 qualifiers from UK Higher Education Institutes, only 28,400 (3.6%) had followed technology courses. Of these, 19,600 qualifiers were UK residents, and amongst these qualifiers, 13,700 had gained an undergraduate degree. This does not reflect well on the UK's capacity to meet future demand. Commenting on demand in 2015, the Tech Partnership (Sambell 2016) also reported that: 42% of employers recruiting technology specialists were already struggling to fill their vacancies, and that these job vacancies amounted to around £2 billion of lost GVA to the UK.

2.1.6 It Starts with Education

In relation to the significant value of the IT sector to the UK economy, the substantial demand for IT professionals, and the skills shortage, it becomes a national imperative to protect the UK's global competitiveness in the IT sector. It was argued by the Royal Society and various other sources that this is *"dependent upon a home-grown, reliable and growing supply of highly skilled graduates with significant deep knowledge in Computing disciplines*"(2012, p.24).

The objective was to inspire future talent to pursue technology-related careers by fostering a pipeline of IT talent in the education system, starting from primary school onwards.

There are a number of contributing factors to the lack of uptake into Higher Education IT courses, and its associated impact on the IT skills shortage. Those factors, the measures taken by the UK government and the Department for Education (DfE) since 2012, and their relative impact are investigated in the next section.

2.2 Digital Technology and Education

2.2.1 The Call for Reform in High-School Computing Education

Computing and ICT education has suffered from the turn of the millennium, both in declining student numbers and enthusiasm for the subject area. The 2012 figures from e-Skills UK show that from 2002 to 2010 applicants for higher education courses increased by 51%; comparatively, during the same period applicants for single subject IT-related courses decreased by 28% (refer to Figure 3) (e-skills UK 2012, p.83).

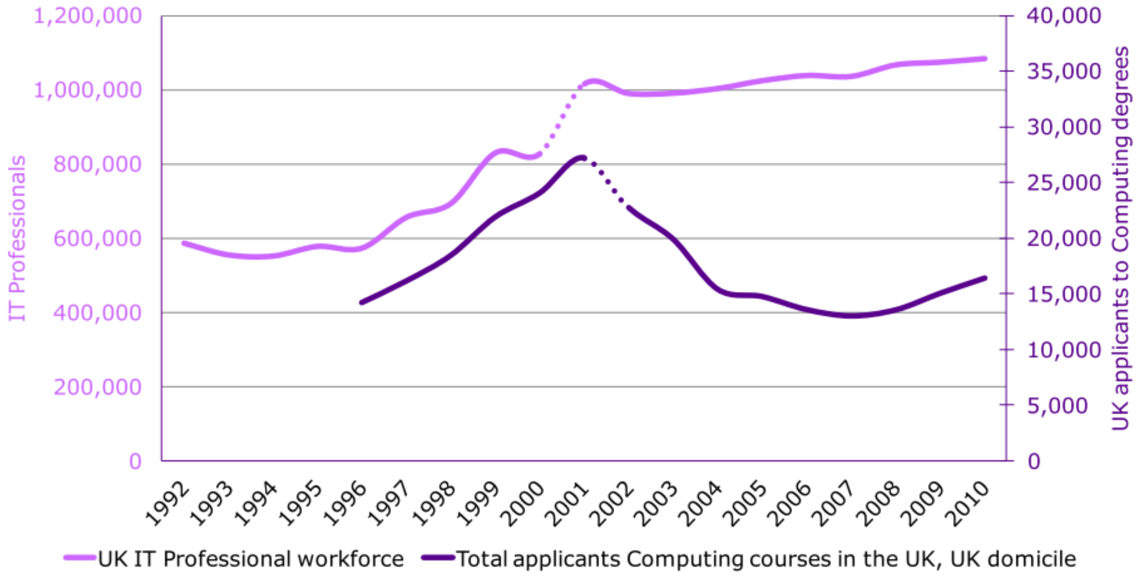

Figure 3: Comparison between the number of IT professionals and applicants to IT-related HE courses, 2002 -2010 (UK domicile)
(e-skills UK 2012, p.84)

In parallel, computing education at Key Stage 4 (GCSE) and Key Stage 5 (A-Level) showed a significant decline in student numbers. Analysis from e-Skills UK showed an overall decline of 43% in Computing and ICT A-Levels, between 2003 to 2011 (2012: 94). Likewise, there was a decline of 70% from 2005 to 2011 in GCSE ICT courses (2012: 95). It should be noted that at that time, there was no GCSE in Computing, and student uptake in A-Level ICT[7] was significantly higher than A-Level Computing.

This decline in student numbers viewed in light of section 2.1's discussion of globalisation, the UK economies dependency on digital technology, the skills gap, and ongoing demand for technology professionals prompted a public call to arms from the BCS, e-Skills UK, The Royal Society, Google, Microsoft and the DfE to reform high-school computing education.

[7] The content of the Computing A-level is more relevant to Computer Science and IT Higher Education and IT-related employment than ICT, which is more focused on end-user skills.

A note of caution must be given, the negative impact of the drop-off in domestic IT HE applicants in relation to the increasing demand for new IT professionals is important, but it should not be overstated. IT-related HE is an important source of talent for the IT sector, but it is not the only source. IT employers actively encourage graduate intake from degrees other than computing or IT, since this affords a healthier workforce mix. Results from the Higher Education Statistics Agency (HESA) for 2010 (e-skills UK 2012, p.86) indicate that of the UK domicile graduates taking up IT & Telecoms roles within six months of leaving university, 50% were from computing, IT and telecoms-related courses and 50% were from other disciplines. This reaffirms the point that IT employers actively encourage graduate intake from other degrees and provides a tentative indicator that some computer science and IT graduates gain employment in other areas.

Additionally, an alternate rational explanation for the trend reversal in applications to computer science HE is the dot-com crash in 2001, which corresponds with the start of the slump (The Royal Society 2012).

It must also be considered that the link between Key Stage 4 and Key Stage 5 education with HE uptake is multifaceted and dependent on the complex interplay of factors such as:

- The incentives given to schools to offer certain subjects (The Royal Society 2012; Computing at School Working Group 2012; Wolf 2011; DfE 2011);
- The number and diversity of vocational qualifications offered at the time (Ofsted 2011; Wolf 2011; The Royal Society 2012);
- The pre-requisites in place for HE courses, and the value placed on high-school qualifications (Computing At School Working Group 2009; The Royal Society 2012; Computing at School Working Group 2012).
- The preparatory value of high-school qualifications versus the potential overlap they may have with the 1st year of HE courses (The Royal Society 2012; Campbell & McCabe 1984; Franklin 1987; Rountree et al. 2004); and
- Public perception of particular high-school qualifications (e-skills UK 2009; The Royal Society 2012).

Despite the above, in public and political media, the root cause of the crisis in computing education was laid squarely on the negative perceptions of ICT at school, poisoning young people's attitude towards computing. It was viewed that ICT teaching in UK schools and colleges was deteriorating and had shifted its focus to the basics of digital literacy. Educational reform was called for in computing education at Key Stage 4 and 5, specifically to refocus away from ICT (digital literacy) towards computer science, with one central initiative being to create a new GCSE in Computing (e-skills 2008; Computing At School Working Group 2009; DCMS & DBIS 2009; e-skills UK 2009; Schmidt 2011; Gove 2012; The Royal Society 2012).

"To bridge the gap in core skills needed for competitiveness, it is essential to encourage students in schools and further education to develop these crucial skills. The proposed introduction of a GCSE in

Computing, the revision of the ICT curriculum at A-level and the introduction of the Diploma have already been raised as important steps in the right direction." (The Royal Academy of Engineering 2009, p.21)

Academically the GCSE in ICT had a strong bias towards IT user skills, meaning it was not directly relevant to A-Level Computer Science, or IT-related HE and careers. The need for ICT qualifications was and is not in debate; it is simply that they hold a different purpose to qualifications in computer science. The exclusive focus on ICT meant that at that time school pupils had, in real terms, fewer opportunities to learn computing than they had been offered 20 years earlier. It was argued that the lack of an alternative to ICT qualifications at Key Stage 4 led to the profound demotivation of those students expecting a computer science focus (CPHC 2009), and that not enough was being done in schools to promote computer science as a degree choice (Mellors-Bourne 2008).

These findings are what led to the existing ICT curriculum being disapplied in 2012, and the announcement of a new focus on Computing and Computer Science GCSEs. At the time, OCR[8] had been piloting a GCSE in Computing, which was being piloted in 2010 and rolled out nationally from September 2011.

2.2.2 Academically Rigorous Computing and Computer Science GCSEs

As outlined previously, one factor affecting the uptake of a qualification is government incentives associated with that qualification. One incentivising mechanism is the English Baccalaureate (EBacc) which is a performance measure for schools (BCS 2012). It is awarded where students attain a grade C or above at GCSE level in five core subject areas: English, Mathematics, History or Geography, a language and the Sciences, of which Computer Science was now included.

On 11 January 2012 at BETT[9], the Secretary of State for Education Michael Gove MP (2012) signalled the intention that if Computer Science GCSEs were created that were academically rigorous, intellectually challenging and offered genuine practical value, then they would be considered for the EBacc. As of December 2013, GCSE Computing and Computer Science qualifications from OCR (2012), AQA[10] (2013) and Edexcel[11] (2013) were accredited for inclusion in EBacc. The inclusion of Computing and Computer science GCSEs in the EBaccs is significant since it: combats the previous negative perception of ICT GCSE by rebranding the Computer Science GCSE as a subject worthy of EBaccs; signals the academic rigour of computer science qualifications; and incentivises schools to promote the computer science qualifications. The latter point is clearly reflected in the fact that, as of 2013 (DfE 2014, p.2), 55.6% of teaching time was spent on EBaccs subjects.

[8] Oxford Cambridge and RSA (OCR) is a qualification awarding body.

[9] British Educational Training and Technology Show

[10] Assessment and Qualifications Alliance (AQA) is a qualification awarding body.

[11] Pearson Edexcel is a qualification awarding body.

2.2.3 Impact on the Teaching Community

The shift towards more rigorous academic subjects, such as computing and computer science, created significant change and impact within the UK high-school teaching community; with relevance to this research, the most important being a:

Shortage of qualified specialist teachers: A variety of sources raise the critical concern that computing and computer science are subjects largely new to secondary schools, and that due to strong demand within industry there is a lack of qualified teachers to teach these subjects (DCMS & DBIS 2009; CAS 2011; CAS 2013; The Royal Academy of Engineering 2009). The Royal Society (2012), using data from the inaugural Schools Workforce Census conducted by the DfE in November 2010, highlighted that of 18,400 ICT teachers in England only 35% had a relevant qualification[12], of which only 25% had both a relevant first degree and a teacher training qualifications. In their report: Shut down or restart? The way forward for Computing in UK schools, they recommend that the government set targets for the number of computer science and IT specialist teachers, and monitor recruitment against these targets.

Lack of Continued Professional Development (CPD) and subject-specific pedagogy: The existing challenges in Continued Professional Development for teachers were further compounded by the significant pressure to re-skill existing teachers towards the new computing curriculum (Sentance et al. 2012; The Royal Society 2012; Pachler 2010). In particular, there was concern over *"a lack of support for CPD that deepens subject knowledge and subject-specific pedagogy in this area, particularly in Computer Science"* (The Royal Society 2012, p.9). The Royal Society (2012) recommended that the government set a minimum level of subject-specific CPD for computing teachers that deepened subject knowledge and subject-specific pedagogy.

Concern over often inadequate technical teaching resources: There have been mixed perspectives regarding technical teaching resources. In 2009, there were positive responses that access to web resources were estimated to yield an increase of approximately ¼ of a GCSE grade in each subject (DCMS & DBIS 2009, p.31). The British Computer Society (BCS 2012) commented that there were suitable educational resources available that enable teachers to effectively teach the concepts of computer science. The Computing at Schools working group (2012) commented that there were fantastic free resources available. Ofsted (2011) reported that in the schools surveyed up to 2011, there was growing use of ICT equipment and materials to enhance learning, and that these investments were changing learning, with a positive response from students. Ofsted reported that "*All the schools visited had made investment in ICT infrastructure, equipment and resources during the period of the survey with notable increases in mobile devices, laptops and virtual learning environments*." (2011, p.46). However, according to e-Skills UK (2009), only a few years earlier, the majority of teachers were complaining that they had to

[12] The Royal Study defined relevant qualifications to be those with JACS codes of G400-G700 plus G900. These codes included degrees in computer science, information systems, software engineering, artificial intelligence and other mathematical and computing degrees.

pull together their own materials or adapt existing resources; that there were insufficient resources to keep students engaged; and not enough time given to teachers to investigate new technologies. In 2012, the Royal Society (2012) commented that technical teaching resources were often inadequate and recommended to the government that appropriate technical resources be made available in all schools to support the teaching of computing.

2.2.4 What has Changed in Five Years?

The Royal Society was instrumental in calls to reform computing education in UK schools, and in giving recommendations toward those reforms; this was embodied in their 2012 report: Shut down or restart? The way forward for Computing in UK schools. Five years later, they published a follow-up report that monitored what progress had been made; this report is called - After the reboot: Computing education in UK schools (Royal Society 2017b). In the latter report, the Royal Society maintained that *"Data and digital technologies promise revolutionary transformational changes across the full range of industry sectors and spheres of life"* (2017b, p.6). However, that high-school computing education in the UK remained patchy and fragile.

In the time since the last report, the subject of computing, encompassing computer science, digital literacy, and information technology (IT) has become mandatory in schools from ages 5 to 16, and has been established as a foundational subject alongside English, Mathematics and the sciences (Royal Society 2017b; Crick 2017). However, the transition has not been easy, and there remains some way to go.

Shortage of qualified specialist teachers: Previously, a critical concern was a lack of qualified teachers to teach computing and computer science principles; the Royal Society (2017b) reported that from 2012 to 2017 England met only 68% of its recruitment target, and in their teacher survey, 44% of secondary school teachers only felt confident teaching the earlier portions of the curriculum, which have less focus on computer science. The Royal Society summarised that teachers were working extremely hard, but that the "*majority of teachers are teaching an unfamiliar school subject without adequate support*" (2017b, p.6).

Lack of Continued Professional Development and subject-specific pedagogy: Previously, CPD was envisaged as a mechanism to bridge the gap in subject-specific knowledge and pedagogy. However, the Royal Society (2017b) reported that that the government had taken a passive role in setting minimum levels of CPD, resulting in a large difference in the CPD hours undertaken by computing teachers. In Scotland, this had been set at 35 hours per year, although it is not required to be subject specific. Whereas, in response to their teacher survey, 26% of English respondents indicated that they undertook zero hours of CPD and 40% had less than nine hours (Royal Society 2017b, p.73). In the five years since the original report, the focus of providing subject-specific pedagogy to school teachers has evolved into the realisation that research is needed to identify pedagogy to teach computer science in schools. The significance of this realisation is discussed in more detail in section 2.2.4.1.

Concern over often inadequate technical teaching resources: The Royal Society (2017b) report that schools have not received ring-fenced funding for technical resources for computing. However, there are several new, free software resources available, and several low-cost hardware resources. The relative increase in technical resources has in turn caused a challenge to teachers in choosing appropriate classroom resources: "*A common refrain in the responses from teachers was that they felt overwhelmed by the abundance of resources and were often unsure of their suitability.*"(Royal Society 2017a, p.77). The Royal Society emphasises the importance of appropriate technical teaching resources, but acknowledges there is a complex landscape of resources available that must align with the curriculum and support the varying knowledge levels of teachers. Citing Falkner and Vivian (2015), Kafai and Vasudevan (2015), and Rich, et al. (2017), Waite (2017) comments that the resources available to teachers typically focus on coding and content, rather than problem-solving and pedagogy; Waite goes further in calling for an audit of the pedagogical foundations of technical resources currently recommended to teachers.

Considering recent sources, the three key factors that prompted this research in late 2013 remain evident, and in some cases have intensified. Furthermore, a highlighted concern of the lack of appropriate pedagogy towards teaching computing in schools gives further impetus to this study.

2.2.4.1 Lack of Research in Computing Education in Schools

In the UK, the new computing curriculum has also resulted in a resurgent research focus on computing education in schools, and in particular the pedagogy for teaching computing in schools (Sentance & Selby 2015; Royal Society 2017a; Crick 2017; Waite 2017). The Royal Society (2017a) contends that:

1. General pedagogical approaches do not tackle the challenges faced by computing teachers and specific computing pedagogies are essential to support effective teaching;
2. Much of the existing research in computing education is focused on higher education; therefore, research is required to ascertain and give evidence of what is effective pedagogy at school level;
3. The relative newness of computing as a subject means associated pedagogies are not as mature as in other subjects; and
4. Theories of learning and instruction should be fundamental to any programme of computing education research.

Sentance and Selby (2015), Waite (2017), and Crick (2017) give support to the Royal Society's assertions that there is a need for pedagogy for teaching computing in schools, and that the majority of existing research has focused on higher education. Sentance and Selby's (2015) classification of research into computer science education in schools from 2005 to 2014 illustrates this aptly. Concentrating on seven journals focused on computing education, they initially identified 2749 papers, and after various academic quality checks, they catalogued 2225 papers. From this base, they identified 420 papers relating to school-aged children and 121 related to teachers (in-service or pre-service). From these 541 papers, only 66 were identified as having pedagogy as a major theme.

An additional area of concern is that literature reviews from Lye and Koh (2014), Sentance and Selby (2015), Waite (2017), and Crick (2017) show concern that most of the existing research is not conducted in a classroom context, and lacks methodological rigour in terms of quality and transferability; typically with regard to sampling, sample size, statistical significance and claimed impacts. Sentance and Selby (2015) go further in commenting that these concerns are not restricted to school/teacher research, but are indicative of the whole field.

2.2.5 Related Research into High-school Computing, E-learning and Pedagogy

As outlined in the previous section, in 2015 Sentance and Selby reported a classification of research into computer science education in schools from 2005-2014 (Sentance & Selby 2015). Dr Sentance provided access to a version of the research classification database for analysis in this study, this analysis is summarised in Table 2.

Filter	NUM of Papers	Comment
None	2,522	All papers included in the research classification database.
major theme = pedagogy then focus = school age students or teachers	58	None of the 58 papers related to pedagogy for computing education in schools give a holistic view of pedagogy. Instead, their focus is on specific aspects of pedagogy, such as: teaching programming; teaching databases, programming with robots; problem-based learning, visualisation, computational thinking, unplugged, handling failure, algorithms, games, collaborative learning, etc.
major theme = pedagogy	432	Two papers have a minimal semblance to the focus of this research in that their focus is on the identification and use of pedagogical patterns for the teaching of computer science.
major theme = pedagogy then minor theme = e-learning	8	None of the papers give a holistic view of pedagogy for computer science e-learning. Instead, their focus was on specific aspects of pedagogy, such as: video casting, visualisation, using videos in programming, online forums as a collaboration tool, use of tablets in the

Filter	NUM of Papers	Comment
		classroom, classroom management, and collaborative learning.
Major theme = e-learning	89	The overriding focus of the identified research is on specific aspects of e-learning. Although, one paper focuses on pedagogical patterns, and one focuses on pedagogy within e-learning; however, the latter focuses specifically on pedagogy for virtual classrooms.
major theme = e-learning then focus = school age students or teachers	4	The four identified papers focus on: learning objectives; e-portfolios; algorithms; and outreach.
major theme = e-learning then minor theme = pedagogy	4	The four identified papers focus on: virtual classrooms; collaborative learning; and programming e-books.

Table 2: Further analysis of Sentance and Selby's classification of research into computer science education in schools from 2005-2014

As Table 2 indicates, there is a severe scarcity of research into computing pedagogy, which is further diminished when considering a school context. This then becomes almost non-existent when considering computing e-learning and schools, or computing e-learning and pedagogy.

The pedagogy literature review (Waite 2017) commissioned by the Royal Society as an addendum to their 2017 report (Royal Society 2017a) concentrates on research in the past 10 years and initially identified over 700 papers, which were eventually reduced to 86 papers focused on computing pedagogy relevant to schools (although not necessarily carried out in a classroom context). That literature review, and the literature review carried out by Crick (2017), give support to the constructivist and social constructivist principles espoused in this research. Notably, no research was discussed that focused on a comprehensive and holistic pedagogy towards computing. Instead, the research was on specific aspects of pedagogy. However, the underlying aspects of pedagogy that were discussed give strong support to the heuristics outlined in this research, since they focus on: scaffolding; kinaesthetic learning; Use-Modify-Create strategy; problem and project-based learning; using demonstrations and tutorials; social aspects of learning; computational thinking; guided discovery; managing cognitive load; worked examples; demonstrating and exemplifying thinking; collaborative learning (programming); and collaborative learning through pupil (peer) support.

The above analysis of recent literature reviews gives a strong indication that research into a comprehensive and holistic set of pedagogical heuristics for teaching, or the design of e-learning software for high-school computer science, is currently an under-researched area. However, the recent literature reviews by Crick (2017) and Waite (2017) gives positive feedback that the heuristics considered in this research study are aligned with pertinent research in this area.

2.2.6 International Comparison

Although the focus of this research is primarily the UK, several countries are engaged in introducing or re-evaluating their computing curriculum in schools. An initial indicator of this can be derived from an analysis of the location of recent research in this field. The classification of computing education research (2005 to 2014) carried out by Sentance and Selby (2015) show that: USA; Israel; Germany; UK; Austria; Slovakia; Switzerland; Italy; Lithuania; and Poland are active in this research area (refer to Figure 4).

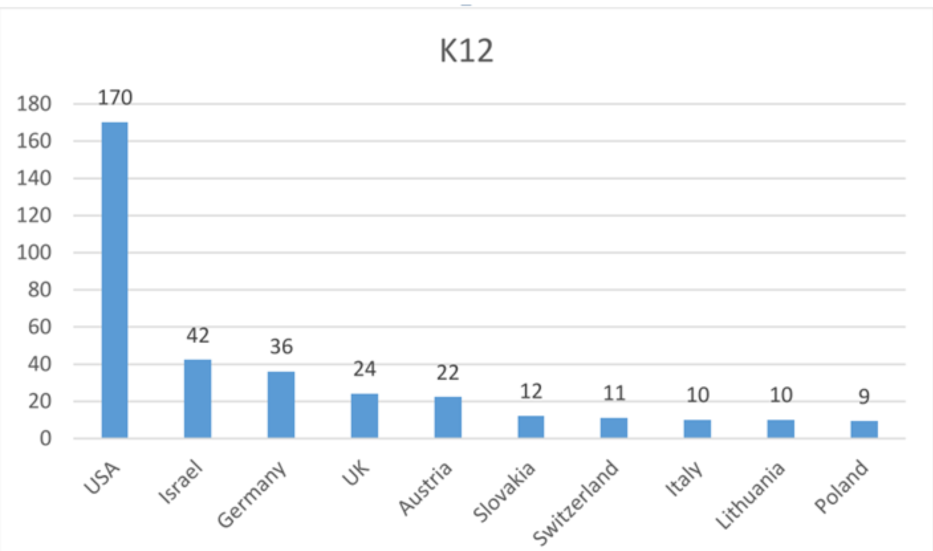

Figure 4: Number of school papers by country of first author

(Sentance & Selby 2015, p.11)

In addition, there are various international comparisons (CAS 2011; Grover & Pea 2013; Snyder 2012; Hazzan et al. 2008; Sturman & Sizmur 2011; Crick 2017) that show that the concerns and challenges outlined in the UK are common to a number of countries. Grover & Pea (2013, p.40) give a succinct summary: *"… 21st-century literacy is gaining momentum globally. Israel has long boasted an exemplary mandatory high school CS curriculum. Countries such as Russia, South Africa, New Zealand, and Australia have already made room for CS in the K–12 curriculum. More recently, the United Kingdom has piloted programs to teach computing to all schoolchildren following a bold 2012 policy charter from the Royal Society."*

There are several national updates and discussions on the status of the computing curriculum in schools. The US at a national level (Stephenson et al. 2005; Wilson et al. 2010; CSTA 2013; ACM et al. 2016), and state level (Ryoo et al. 2013; Ericson et al. 2016; Guzdial et al. 2014), New Zealand (Bell et al. 2010;

Murugesh et al. 2010; Bell 2014; Bell et al. 2012), Australia (Egger et al. 2012; Falkner & Vivian 2015), Israel (Hazzan et al. 2008; Armoni & Gal-Ezer 2014; Gal-ezer & Stephenson 2014), Germany (Brinda et al. 2009; Hubwieser et al. 2011), France (Baron et al. 2014), Italy (Bellettini et al. 2014), Sweden (Rolandsson & Skogh 2014), Belgium (Martens & Hofkens 2013), Russia (Khenner & Semakin 2014), and India (Raman et al. 2015) are all in varying stages of similar initiatives to give greater prominence to the high-school computer science curriculum. These countries range between those with a well-established computer science curriculum in schools, to those in their infancy; each country inheriting their own individual set of difficulties, but with a common thread of challenges in transitioning teachers to a new curriculum, ensuring teachers have both subject and pedagogical knowledge to support their teaching, and the relevant teaching resources to support student instruction. It therefore follows that the findings of this research are broadly transferable to such initiatives in other nations.

2.3 E-learning Software

In view of the challenges faced in computing education outlined in section 2.2, one approach to support teachers and high-school computing is the increased usage of e-learning software (technical resources).

There are varying definitions of e-learning; however, in the broadest sense, e-learning is electronic learning, and as such utilises electronic technology to facilitate the learning process. Historically, the communication medium for e-learning has ranged through television, videotape, CD-ROM, DVD, etc. (Ozkan & Koseler 2009; Shee & Wang 2008). However, in recent years, it has become synonymous with the distribution of course material and content through computer networked technology (i.e. the internet) (Welsh et al. 2003). The implementation of e-learning can vary in complexity to include "*a number of integrated tools and services for teaching, learning, communicating, and managing learning material*" (Ardito et al. 2006), and citing the European Commission, Alptekin and Karsak (2011) emphasise the improved quality of learning via multimedia technologies and services to support collaboration.

Within the context of this study, e-learning is regarded as software that delivers **content** and **instructional methods** to facilitate learning, ideally in an engaging and interactive manner. Furthermore, in the context of high-school computing, such software should cover a complete topic or non-trivial portion of curriculum (e.g. algorithms, programming, data representation, networks, etc.). This differentiates e-learning software from the multitude of elemental digital resources found online that can be used individually to support a small fraction of the computing curriculum.

2.3.1 The Status of E-learning

Investment in, and the growth of e-learning usage, have been widely reported as two of the most rapidly expanding areas of education and training (Gilbert et al. 2007; Anderson 2008; Jang 2009; Ozkan & Koseler 2009; Zaharias & Poylymenakou 2009; Jung 2011); furthermore, e-learning is touted as a new paradigm for modern education (Sun et al. 2008). According to the 2017 State of the Industry Report (ATD Research

2017) from the Association of Talent Development (ATD), e-learning accounted for 45% of training delivery in 2016, of which the most popular type of technology-based learning was self-paced e-learning.

The picture in school environments, whilst positive, is a little more complex to interpret; various studies report on national / government initiatives to promote e-learning and the broad general support for e-learning in schools (Gilbert et al. 2007; Boulton 2008; Jang 2009; Liu et al. 2011; Pardamean & Suparyanto 2014).

The US Department of Education's 2004 National Educational Technology Plan is cited (Livingstone 2012; Pardamean & Suparyanto 2014) in relation to the widespread implementation of e-learning in K-12 education, such as: 15 US states providing some form of virtual schooling to supplement regular classes; hundreds of thousands of students taking advantage of e-learning in 2004; and about 25% of all K-12 public schools offering some form of e-learning or virtual school instruction. Citing various sources, Kim et al. (2014) report that: in the academic year 2007/8 in the US, over 1 million school students took online courses; that in the following five years it was estimated that 5 million students would take online courses; and that in 2011, all but one state had virtual schools. More recent reporting from the Evergreen Education Group (2017) is not directly comparable, but do not seem to support the growth predictions from Kim et al. (2014); instead, for 2016, the Evergreen Education Group reports: 24 US states with virtual schools; 934,968 course enrolments; and 511,251 students taking online classes.

Focusing on the UK, Livingstone (2012) cites BECTA[13] in reporting that in the academic year 2008/9, UK schools spent some £880 million on ICT, and that almost half of all primary school pupils used digital resources at least once a week; this falls to one in ten in secondary schools.

In 2006, the European Commission reported that most schools in Europe were in the early phase of ICT adoption with patchy provision and use, and hence could not report significant improvements in learning and teaching. Nevertheless, a small percentage of schools were able to effectively embed ICT into their curriculum, thereby transforming teaching and learning across a wide range of subject areas. Based on the latter, the ICT Impact Report (Balanskat et al. 2006, pp.3–4), directly recounts a number of quantitative benefits of ICT adoption and e-learning, such as:

1. *"ICT impacts positively on educational performance in primary schools (with varying effect per subject)"*;
2. *"Use of ICT improves attainment levels of school children in English - as a home language - (above all), in Science and in Design and Technology between ages 7 and 16, particularly in primary schools*";
3. *"Schools with higher levels of e-maturity demonstrate a more rapid increase in performance scores than those with lower levels"*; and

[13] British Educational Communications and Technology Agency

4. *“Schools with good ICT resources achieve better results than those that are poorly equipped”*.

Additionally, the report offers a number of qualitative findings, that are summarised below:

1. Pupils, teachers and parents consider that ICT has a positive impact on pupils’ learning;
2. Pupils’ subject-related performance and basic skills (calculation, reading and writing) improve with ICT, according to teachers;
3. Teachers are becoming more and more convinced that the educational achievements of pupils improve through the use of ICT;
4. Academically strong students benefit more from ICT use, but ICT also serves weak students; and
5. Teachers in Europe state that pupils are more motivated and attentive when computers and the internet are used in class.

In their 2009 repo*rt:* The impact of digital technology (Underwood 2009), BECTA reported a growing body of national and international evidence demonstrating the positive impact of digital technologies on learning outcomes. They reported improvements in attainment at Key Stage 1 and 2 due to ICT, and the following improvements in secondary school (2009, p.3):

1. *“The equivalent to a term’s additional progress in KS3 science”*;
2. *“An average gain in GCSE science equivalent to 52,484 students moving from grade D to C. Improvements to the overall percentage of pupils 5+ A*- Cs at GCSE in the year after broadband introduction”*; and
3. “*After controlling for KS3 results, the availability of a computer at home significantly positively associated with Key Stage 4 test scores. That association amounted to around 14 GCSE points (equivalent to 2 GCSE grades)*”.

They also reported a wider outcome that classes with online learning (either completely online or blended) on average yielded stronger learning outcomes than traditional face-to-face learning.

A meta-analysis of online learning studies commissioned by the US Department of Education (Means et al. 2009), reported slightly more cautious benefits as compared to the European Commission and BECTA reports. Analysing studies from 1996 through to July 2008, Means et al. identified that there was a small number of published studies relating to K–12 students; therefore, caution was advised in generalising to the K–12 population. They reported that:

1. *“Students who took all or part of their class online performed better, on average, than those taking the same course through traditional face-to-face instruction.”* (Means et al. 2009, p.xiv)
2. *“Instruction combining online and face-to-face elements had a larger advantage relative to purely face-to-face instruction than did purely online instruction.”* (Means et al. 2009, p.xv)

However, again Means et al. cautioned that the observed advantage of online learning may have been a product of the treatment conditions and not the instructional delivery. Likewise, the increased effect size of blended learning may have also been caused by aspects of the treatment and control conditions, such as: curriculum material; aspects of pedagogy; and learning time.

Other research has been even more cautious in relation to e-learning; in the early days it was noted that consumers were blinded by the possibility of technological innovation into assuming e-learning would implicitly be educationally effective (Reeves 1994). In fact, at that time, e-learning material was frequently of poor to moderate quality, often an electronic transposition of existing material, and often overly focused on aesthetics to the detriment of usability and pedagogy (Reeves 1994; Wesson & Cowley 2003; Dringus 1995; Ardito et al. 2004). Lanzilotti and Ardito (2006) and Boulos et al. (2006) comment that despite the large number of available e-learning systems, there were concerns over quality. Although there are a variety of contributing factors, Rovai (2002), Zaharias and Poylymenakou (Zaharias & Poylymenakou 2009), Boyle et al. (2010), and Alptekin and Karsak (2011) all show concern over the high dropout rates in distance learning, and postulate that a major contributor to this is the poor quality of e-learning applications (Zaharias & Poylymenakou 2009).

E-learning research focused in schools mirrors many of the aforementioned concerns; Underwood (2009) and Boulton (2008) report concerns over poor quality outdated e-learning material that was not aligned with the expectations of the pupils of the day. Additionally, they linked the effectiveness of e-learning with the alignment of technology affordances and pedagogy.

The students level of e-maturity is a recurring theme with school-focused research, showing that students need to be trained in the skills to effectively participate in e-learning, and supported throughout (Underwood 2009; Boulton 2008; Jang 2009; Sendall et al. 2008).

Boulton's (2008) study on GCSE ICT e-learning showed concerns over poor quality e-learning material, and a lack of preparation and support from the school, leading to students lacking the skills and motivation to participate in e-learning. Ultimately, these factors led to low satisfaction from the students, and a high dropout rate.

Lastly, Condie and Munro (2007), Livingstone (2012), and Kim et al. (2014) take a more critical view of the evidence towards improved pupil attainment through e-learning/ICT, commenting that it is inconsistent (and unconvincing). Condie and Munro (2007, p.4) remark that *"it does appear that, in some contexts, with some pupils, in some disciplines, attainment has been enhanced."* However, the overriding concern is that much of the evidence is taken from small-scale studies lacking the rigour and scale by which generalisations can be drawn.

2.3.2 Quality of E-learning Software and the Need for E-learning Heuristics

Despite the aforementioned caution and scepticism, there remains a strong support for e-learning, but it is tempered with a more realistic view. Although e-learning software has become mainstream, a concern still remains that what is delivered can often fall short (Alonso et al. 2005; Alonso et al. 2009; Chan &

Robbins 2006). Unsurprisingly, content quality is the most important concern (Sun et al. 2008). Alonso et al. (2005, p.218) protest that *"there is a serious dysfunction between the profusion of technological features that are put forward and the shortage or non-existence of teaching principles for e-learning."* Chan and Robbins (2006) advise that e-learning software "*require(s) an understanding of educational pedagogy and instructional design and demand(s) a considerable amount of planning and preparation*"(p.496). Echoing this sentiment, Hadjerrouit (2010) argues there is often a lack of "*pedagogical usability*" in existing e-learning software, and a lack of alignment with education needs and standards.

More recent studies in New Zealand (Murugesh et al. 2010), Morocco (Abderrahim et al. 2013), and Australia (Falkner & Vivian 2015) evaluated e-learning resources used within their respective high-school curricula; they reported evaluation results ranging from broadly positive to concerns over resources of low or medium quality. In the UK, the Royal Society (2017a) has called for greater support to be given to teachers in the selection and usage of suitable quality computing resources, and in their pedagogy literature review recommended, as a high priority, an audit of the pedagogical foundations of e-learning resources currently recommended in the high-school computing curriculum (Waite 2017).

There are several factors that contribute to the quality, and educational effectiveness, of e-learning. Quality is defined by the Oxford English Dictionary as "*The standard of something as measured against other things of a similar kind; the degree of excellence of something*." Jung (2011) argues that the majority of studies on e-learning quality are from the perspective of e-learning providers, assessors, governments and professionals, but do not focus on learners or learning. This is peculiar since quality is also defined by various authors as "*fitness for purpose*" (Campbell & Rozsnyai 2002; Harvey & Green 1993; Vlăsceanu et al. 2004; Woodhouse 2004) and the purpose of e-learning software is learning. Therefore, in the context of this research on e-learning software, quality focuses on the standard and degree of excellence of the pedagogy that underpins the learning process. There is a wide body of research that contends that pedagogy is one of the most critical underpinning factors in e-learning, and that, as already outlined, this factor is often lacking (Govindasamy 2001; Wesson & Cowley 2003; Ardito et al. 2004; Zenios et al. 2004; Lanzilotti & Ardito 2006; Ardito et al. 2006; Sun et al. 2008; Anderson 2008; Hsu et al. 2009; Ozkan & Koseler 2009; Underwood 2009; Zaharias & Poylymenakou 2009; Alptekin & Karsak 2011; Ofsted 2011; Zaharias & Koutsabasis 2012; Abderrahim et al. 2013; Kim et al. 2014; Falkner & Vivian 2015; Waite 2017; Alonso et al. 2005).

There are a variety of texts on e-learning instructional design; the research of this thesis supplements existing literature by providing an accessible set of heuristics for e-learning pedagogy. Heuristics are specific rules-of-thumb or arguments derived from experience. They are consolidated and condensed to provide the essence of e-learning pedagogy to the teacher audience. Existing e-learning heuristics are extended to focus more tightly and in-depth on pedagogy, due to the aforementioned concerns on e-learning quality and, in particular, the specific concerns on the underpinning pedagogy of some e-learning resources. In addition, a more in-depth focus on pedagogy is necessary since originally, research on e-learning heuristics focused almost entirely on usability with little reflection of the complexities of the learning process (Dringus 1995; Parlangeli et al. 1999; Wesson & Cowley 2003; Dringus & Cohen 2005; Mehlenbacher et al. 2005; Hsu et al. 2009; Zaharias & Poylymenakou 2009). However, research has matured, and it is now accepted that the value of e-learning software directly relates to its pedagogical value. This is reflected in a body of research that builds upon Nielsen's usability heuristics, and supplements it with pedagogical usability heuristics (Reeves et al. 2002; Squires & Preece 1999). However, there still seems to be a sense that pedagogy is an adjunct to usability (or other factors) instead of being the primary focus of the heuristics. Nokelainen (2006) concludes that pedagogical aspects for designing or using digital learning material are much less frequently studied than technical ones, and at that time, the studies that existed were theoretical in nature and had not undergone a process of empirical testing. Gilbert et al. (2007) contend that there are a number of implicit and explicit frameworks designed to inform e-learning practice; however, the components of these frameworks cover a variety of contributing factors, of which pedagogy is treated as one of many factors. Their discussion of pedagogy also reflects that researchers have focused on specific pedagogical aspects of e-learning, rather than a holistic pedagogy for e-learning; focus areas include: online communities, e-assessment, judging text on screen, asynchronous collaborative learning, e-learning dialogues, social dimensions of online learning, etc. Dabbagh (2005) offers the closest conceptual alignment with the objectives of this study, by offering pedagogical models for e-learning that are presented as a theory based framework for e-learning design. Dabbagh's study does not specify the framework to the level of detail specified in this research and is limited to a theoretical perspective; nonetheless, it holistically covers a number of pedagogical areas also covered in this study, such as: promoting authentic learning; supporting role-playing; promoting articulation and reflection; promoting collaboration and social negotiation; supporting multiple perspectives; supporting modelling and explaining; and providing scaffolding.

The literature review carried out in this study reflects that despite the acknowledgement that pedagogy is critical for e-learning design, there is a scarcity of e-learning heuristics that give adequate focus to pedagogy. This is further supported by the fact that the overwhelming majority of e-learning heuristics are dual purpose; they are intended for design and also for the evaluation of e-learning software. The review of e-learning evaluation heuristics in section 2.3.3 also clearly shows the bias towards usability at the expense of pedagogy. This scarcity of pedagogical heuristics is further evidenced by the review of literature presented in section 2.2.4.1; which shows a lack of pedagogy defined for high-school computing. Considering these factors, at the time of writing (January 2018) this study has not identified an equivalent holistic set of heuristics focused on e-learning software for high-school computing.

2.3.3 E-learning Evaluation Protocols

As is the norm, the pedagogical heuristics and criteria defined in this study are dual purpose: to guide the pedagogical design of e-learning software, and to serve as the basis of a protocol to guide the evaluation of such software (Ardito et al. 2006; Masip et al. 2011).

Following on from the previous section, the bias towards usability, often neglecting pedagogy, is further evident in the development of e-learning evaluation protocols. The need for usability in software is indisputable, and springing from this need, the evaluation of educational software has largely been focused on usability. Lanzilotti and Ardito (2006) acknowledge this point and go one step further in echoing the widely held sentiment that usability in e-learning software is particularly important: "*If an e-learning system is not usable, the learner spend more time learning how to use the software rather than learning the contents*"(2006, p.42). This study unequivocally agrees with the need for usability in e-learning software and proposes it as a mandatory prerequisite for learning, but usability is not enough. Analogous to Herzberg's (1987) motivation-hygiene theory, usability can be viewed as a hygiene factor whose absence will cause dissatisfaction and hinder learning, but in itself it does not stimulate learning. Pedagogy is the motivational factor that encourages learning; therefore, e-learning software must be effective in meeting the intended pedagogical objectives.

Squires and Preece (1996; 1999), Parlangeli et al. (1999), Zaharias et al. (2002), Wong et al.(2003), Lanzilotti and Ardito (2006), Zaharias and Poylymenakou (Zaharias & Poylymenakou 2009), Zaharias and Koutsabasis (2012) and Abderrahim (2013) all concur that the evaluation of e-learning software deserve special attention and that such an evaluation must integrate the assessment of the educational quality of the software. Moreover, Lanzilotti and Ardito (2006), citing Parlangeli et al. (1999), Squires and Preece (1999) and Wong et al.(2003), argue that typically the e-learning evaluation criteria are stated vaguely, leaving the evaluation measurement open to subjective interpretation. Grützner et al. propose that e-learning software development must consider "*content and instructional issues; management; technical and graphical issues…*" (2004, p.946). Considering Grützner et al.'s broad classification, this study considers that a foundation of usability must already exist to resolve potential technical and graphical issues. This frees the proposed evaluation protocol to focus more specifically on educational content and instructional design (pedagogy). According to Squires and Preece (1996) the separation of usability evaluation and educational evaluation, as outlined in this research, is somewhat artificial since "*the design of an interface supports certain styles of interaction which may or may not support the intended learning tasks*"(1996, p.16). There is merit to this argument; however, considering the relative glut of research on usability heuristics and evaluation, and the lack of focus on educational value and pedagogy, the research presented in this thesis has purposely restricted its focus to the latter.

Reeves (1994) was one of the original advocates for comparative evaluations, and the development of criteria for evaluating computer-based education. More recently, this need is reflected in a school context, by the evaluation of e-learning resources carried out by Murugesh et al. (2010), Abderrahim et al. (2013), and Falkner and Vivian (2015). These e-learning evaluations highlight the need for a rigorous e-learning evaluation protocol that gives focus to pedagogy.

Murugesh et al. (2010), carried out an evaluation of online and offline resources to support New Zealand's high-school transition towards a more computer science focus. They evaluated the resources in accordance with the learning objectives of the three levels of the curriculum; however, it is important to note that there is no mention of any pedagogical evaluation.

In contrast, Abderrahim et al. (2013) express a focus on pedagogy in their evaluation of commercially produced digital education resources for the Moroccan education system. They formed their evaluation as a 20-question checklist that gives focus to pedagogy and some focus to content appropriateness, but does not offer an encompassing protocol to guide the evaluation. The evaluation process is intended to provide quantifiable results, but the checklist is defined at a very high-level, and without supporting evaluation criteria, so that any results are open to interpretation. Examples of these checklist questions include (Abderrahim et al. 2013, p.32)[14]:

1. Is the information presented relevant?
2. Structuring the resource she promotes its use in an pedagogical context?
3. Does the product include stimuli likely to promote learning?
4. Does the tool present activities creating interactions between learners?
5. Is there a match between the audience, content and objectives?

Falkner and Vivian (2015) were commissioned by the Australian government to undertake an evaluation of the educational quality of online computer science resources, and to ascertain their suitability for K-12 classroom learning and teaching. Their Quality Assessment Framework was developed in consultation with the Australian Department of Education and Training and gave a partial focus on pedagogy, including such aspects as: authenticity, accuracy, currency, consideration of prior learning, scaffolding and learning styles, provision of open-ended tasks, reflection, community, and collaboration. In addition, the evaluation was intentionally targeted towards computer science, and mapped to the Australian curriculum. However, ultimately, the evaluation was again marred by several limitations. The evaluation was grouped into four principal areas, with some description of underlying evaluation elements, but was not specified at a level of detail to support a clearly objective evaluation. Furthermore, a rigorous protocol to guide the evaluation steps was not presented, there was limited coverage of pedagogical principles and the measurement of evaluation elements was coarsely defined as: No, Somewhat, and Yes.

These recent studies reflect a need for the evaluation of digital education resources; but the inherent limitations of each of the evaluations also reflect the need for a rigorously defined evaluation protocol focused on pedagogy. Considering the UK's (Waite 2017) recent call to evaluate the pedagogical foundation of their high-school digital education resources, this need is likely to continue.

The literature review outlined in this section, acts as a foundation and is elaborated in Chapter Five, which discusses the synthesis of the e-learning evaluation protocol.

[14] Grammar is intentionally not corrected on the checklist items.

2.4 Learning Theories and Other Inputs into the Pedagogy

The e-learning pedagogy developed in this study, aims to provide a set of heuristics and guiding criteria, for the design and evaluation of e-learning software (including the supporting use of a collaborative learning environment), for use in the instruction of high-school computer science. It is therefore natural that these heuristics are based on research and theories of how we learn best.

2.4.1 What are Learning Theories?

There are a variety of definitions for what learning is, and what learning theories are. According to the Merriam-Webster (2017) dictionary, a theory is "*a plausible or scientifically acceptable general principle or body of principles offered to explain phenomena.*" In this case, the phenomena we seek to explain is learning. Likewise, with reference to Table 3, Alan Pritchard (2009, p.2) gives a selection of definitions for learning, that each touch upon the different aspects of learning.

A change in behaviour as a result of experience or practice
The acquisition of knowledge
Knowledge gained through study
To gain knowledge of, or skill in, something through study, teaching, instruction or experience
The process of gaining knowledge
A process by which behaviour is changed, shaped or controlled
The individual process of constructing understanding based on experience from a wide range of sources

Table 3: Definitions of learning

A working definition for learning theories can therefore be formed as:

"A scientifically acceptable general principle or body of principles to explain how humans gain knowledge of, or skill in, something through study, teaching, instruction or experience."

2.4.2 Choice of Learning Theories and Inputs into the Pedagogy

The seemingly simple and instinctive process of learning is actually very complex. There is a significant body of research into learning theories, e-learning and STEM education. However, this significant body of knowledge is somewhat overwhelming; there are complementary and competing learning theories, and differing research into the best implementation of these theories in technology (Illeris, 2009). Although it has a more commercial perspective, the website https://www.learning-theories.com/ is adequate in giving a conservative indicator of the size of the learning theory space, it lists over 90 distinct learning theories. An extract of some of the more well-known theories is listed in Table 4.

ADDIE Model of Instructional Design ARCS Model of Motivational Design (Keller) Bloom's Taxonomy (Bloom) Classical Conditioning (Pavlov) Cognitive Apprenticeship (Collins et al.) Cognitive Dissonance (Festinger) Cognitive Load Theory (Sweller) Cognitive Theory of Multimedia Learning (Mayer) Communities of Practice (Lave and Wenger) Connectivism (Siemens, Downes) Constructivism (Piaget)	Discovery Learning (Bruner) Distributed Cognition (Hutchins) Elaboration Theory (Reigeluth) Emotional Intelligence (Goleman) Experiential Learning (Kolb) Expertise Theory (Ericsson, Gladwell) Flow (Csikszentmihalyi) Game Reward Systems Gamification in Education Gestalt Theory (von Ehrenfels) Grit (Duckworth, Matthews, Kelly, Peterson) Intrinsically motivating instruction (Malone) Maslow's Hierarchy of Needs (Maslow)	Model of Hierarchical Complexity Montessori Method (Montessori) Multimodality (Kress) Multiple Intelligences Theory (Gardner) Online Collaborative Learning (Harasim) Operant Conditioning (Skinner) Psychological Behaviorism (Staats) Situated Learning Theory (Lave) Social Constructivism (Vygotsky) Social Network Analysis (Scott, Prell) Stage Theory of Cognitive Development (Piaget)

Table 4: Indicative listing of learning theories

Although not a learning theory, the work of Knud Illeris (2003; 2009), in providing a framework in which learning theories can be contextualised, is valuable. Illeris posits that learning is based on two processes: an external interaction process and an internal acquisition process. These are then modelled across the dimensions of content, incentive and environment (refer to Figure 5). This framework is necessary since many learning theories deal with only one of these processes, and therefore give an incomplete picture of how learning occurs.

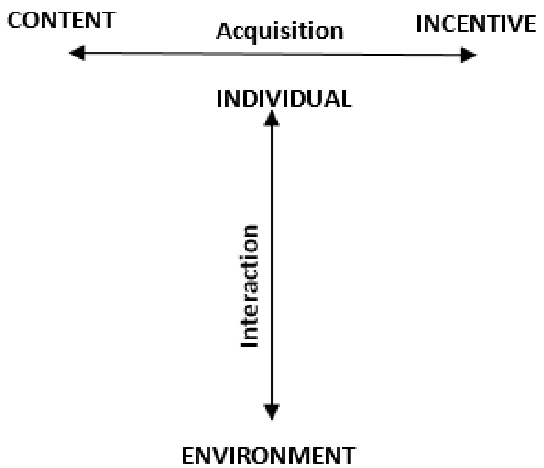

Figure 5: The fundamental processes of learning
(Illeris 2009, p.9)

The first learning process is an external *"Interaction"* process between the learner and their social, cultural or material environment. This interaction with the external environment provides the initial stimulus for learning and allows the learner to integrate into communities and society in general. The interaction process involves action, communication and cooperation, and takes varying forms such as perception, transmission, experience, imitation, activity and participation.

The external stimulus then feeds into an internal psychological process of elaboration and acquisition. This internal process focuses on managing the learning content and maintaining the incentive (motivation) to devote mental energy to learn. The content dimension focuses on identifying meaning and building understanding from the incoming information in such a way that it increases the learner's overall abilities. However, such processes require significant cognitive effort, so there is a need for an incentive dimension that provides and directs the mental energy to support learning. This dimension aims for mental equilibrium and involves the learner's motivation, volition and emotions.

Whilst academics debate the relative merits and weaknesses of certain learning theories, or the superiority of other theories (Bell 2011; Kop & Hill 2008; Siemens 2006; Verhagen 2006; Vogel-Walcutt et al. 2011; Vrasidas 2000), this study aligns with Illeris (2009) and Anderson (2008) in asserting that the various learning theories are not mutually exclusive. Aspects of various learning theories can be synthesised to create a pedagogy that supports the whole learning process. As a theoretical foundation, the pedagogy proposed in this thesis synthesises the following well established learning theories and one learning style theory.

1. Constructivism,
2. Social Constructivism,
3. Connectivism,
4. VARK Learning Styles,
5. Cognitive Load Theory, and
6. ARCS Model of Motivational Design

As previously mentioned, these theories were selected primarily so that their synthesis can provide comprehensive coverage across the three dimensions of content, incentive and environment. Additionally, their selection was due to their maturity, and the availability of research that discusses the theory, its effective implementation, and offers evidence of the theory's positive effect on learning and motivation. Furthermore, consideration was given to contemporary theories (e.g. connectivism), which give more focus to technology and our current digital society. Finally, in keeping, with a focus on e-learning, technology, and high-school computer science, the pedagogy was also informed by research in the areas of:

1. e-learning best practice,
2. collaborative learning,
3. gamification, and

4. computational thinking.

The following subsections explore at a high-level these learning theories and the additional pedagogical inputs. This is then followed by Chapter Four, which gives further information on how these theories are synthesised into a holistic set of heuristics.

2.4.3 Constructivism

Traditional objectivist (behaviourist) approaches contend that there is one true and correct reality, which can be taught to a learner. In contrast, constructivist approaches recognise a real-world that sets limits on our experiences, but proposes that there is no uniformly perceived single reality; in fact, each person's perception of reality is a mental construct founded on interpretation of their interactions with the world (Brooks & Brooks 1999; Jonassen 1999; Vrasidas 2000; Pritchard 2009). An individual's reality is therefore based on their existing experience and understanding, which is in turn used to make sense of their current perception of events. The mental constructs that organise and categorise our skills, and knowledge and understanding of the world are called schema (Brooks & Brooks 1999).

In this light, constructivists view learning as the result of active mental construction, where new information is built into an individual's current mental models (schema). Piaget (1969), one of the founding fathers of constructivism, proposes that external experience can reinforce existing mental models or contradict them, leading to the following:

- **Assimilation** – the process by which new information reinforces an existing schema, and the schema is augmented with new information.
- **Accommodation** – the process by which existing schemas must be altered to cope with new experiences that contradict the existing mental model.
- **Equilibrium** – the process of arriving at a stable state where there is no longer conflict between new and existing knowledge.

Constructivist principles are claimed to offer several learning benefits (Hattie 2009), including:

- Better and deeper understanding since it emphasises authentic and active learning (Kolb 1984; Brooks & Brooks 1999; Jonassen 1999; Fadel & Lemke 2008; Melero et al. 2012; Hattie 2009);
- An increase in motivation since students feel more in control, and are closer to their perceived reality (Kolb 1984; Brooks & Brooks 1999; Hidi & Harackiewicz 2000; Palmer 2005; Bertacchini et al. 2012; Melero et al. 2012);
- An increase in social skills since constructivism focuses heavily on interacting, perceiving and interpreting the world, often through dialogue (Brooks & Brooks 1999; Jonassen 1999; Karagiorgi & Symeou 2005; Melero et al. 2012); and
- A focus on the big picture, promoting problem-solving and higher-order thinking (Brooks & Brooks 1999; Jonassen 1999; Jonassen & Hung 2008; Hadjerrouit 2005; Liu et al. 2011).

However, there are also counter-arguments that counsel a measure of caution (Perkins 1991; Perkins 1999; Brooks & Brooks 1999; Hadjerrouit 2005; Karagiorgi & Symeou 2005; Siemens 2008; Kirschner et al. 2006; Vrasidas 2000; Vogel-Walcutt et al. 2011; So 2002), and raise concern over the complexity of implementing a curriculum using constructivist approaches, and the challenge for teachers to transition from instructivist to constructivist approaches. There are warnings over the learner's ability to construct their own knowledge, and that the perceived lack of guided instruction in constructivist approaches can allow learners to create their own "*private universe*" to explain complex phenomena. This in turn calls into question the accountability that what students learn is aligned with expected learning outcomes. Additionally, there are significant concerns over the additional cognitive load expended by students within constructivist approaches (Vogel-Walcutt et al. 2011). In a comparative analysis of objectivist and constructivist approaches, Vrasidas (2000) acknowledges that some learners may find constructivist approaches intimidating and complex, and in some learning contexts, didactic instruction may be more appropriate. Such concerns are to some extent valid if considering extreme constructivist positions, in which students have almost unlimited discretion to structure their own learning. It is for this reason that the proposed pedagogy takes a moderate constructivist strategy (Vrasidas 2000; Karagiorgi & Symeou 2005; Alonso et al. 2009) in which constructivist values are translated into more concrete instructional design principles, or in the case of this study, into specific e-learning heuristics.

It is important to note that in the US, the national teacher associations have endorsed constructivist lesson design and instructional practices, and that constructivist approaches underlie the US National Research Council's proposal that active learning is adopted in schools (Brooks & Brooks 1999; Crick 2017). Furthermore, a recent literature review commissioned by the Royal Society to summarise what is known about pedagogies for teaching computing in schools, recognises that: constructivist principles have had a wide-ranging impact on learning theories and teaching methods; have been an underlying theme of many education reform movements across the world; and have been proposed as a suitable pedagogy for computer science, and in particular for computer programming (Crick 2017). This advocacy of constructivist approaches is with the full recognition that there remains debate regarding the tension between constructivist exploration and the controlled progression of the teaching of more complex concepts (Waite 2017). It is with recognition of this tension and debate, and moderate constructivist approaches, that these heuristics take a moderate line in which students should construct their own knowledge but should also be given instructional guidance and support via the e-learning software and their teachers.

2.4.4 Social Constructivism

As its name implies, social constructivism is closely related to constructivist principles; both theories are based on knowledge being actively constructed. However, constructivism focuses on knowledge construction *"in the head of the learner"* (intra-psychological), while social constructivism proposes that knowledge is created through social interaction (inter-psychological), often with a more knowledgeable other (Vrasidas 2000; Barbour & Rich 2007; Pritchard 2009). Although each theory has its own perspective on exactly when and where knowledge is constructed, they are complementary (Cobb 1994). An individual's current knowledge forms the basis of their contribution to the dialogue. Then through this dialogue, new shared knowledge is constructed and is then assimilated by the individual learners, which in turn feeds into the next cycle of social interaction (Dillenbourg et al. 1995; Kop & Hill 2008).

Vygotsky (1978; 1986), one of the earliest proponents of social constructivism, suggested two key components in learning: *"language"* and *"scaffolding"*. According to Kop and Hill (2008) Vygotsky postulated that self-talk (language) allowed children to work through complex problems by externalising them as a form of self-guidance and self-direction. This in turn forms the basis of learners' externalising problems through language and social interaction. Language becomes the form for communicating ones existing knowledge and entering into dialogue with others to solve a problem.

The second critical component within social constructivism and Vygotsky's work, is scaffolding; the process by which supportive interactions between the learner and a more knowledgeable other enable the student to achieve something beyond his or her existing capabilities. The aforementioned knowledge or activity that is just beyond the learner's current independent efforts is in the learner's Zone of Proximal Development (ZPD) (Vygotsky 1978).

Working at the ZPD stretches the learner's existing capabilities and encourages them to the next higher level of learning, which is postulated by Vygotsky (1978) to improve students developmentally[15]. The focus on social interaction promotes higher order thinking by encouraging learners to develop, evaluate, and appreciate multiple perspectives on an issue. Furthermore, the underlying principles and collaborative nature of social constructivism also leads to greater student engagement, and learning that is more meaningful.

2.4.5 Collaborative Learning

Closely aligned with social constructivism is collaborative learning. There is a significant body of research that discusses and broadly supports collaborative learning (Johnson et al. 1984; Roger & Johnson 1988; Jonassen 1999; Vrasidas 2000; Zenios et al. 2004; Nuutila et al. 2005; Palmer 2005; Black & Wiliam 2009; Hattie 2009)**;** this in turn has been extended into the realm of technology-assisted collaborative learning (Lebow 1993; Squires & Preece 1999; Lou et al. 2001; Mayes & de Freitas 2004; Karagiorgi & Symeou 2005; Anderson 2008; Sun et al. 2008; Tutty & Klein 2008; Nicholas & Wan 2009; Papanikolaou & Boubouka 2010; Hadjerrouit 2010; Kang et al. 2010; Clark & Mayer 2011; Jenkins et al. 2012). Furthermore, it is argued that technology-assisted collaborative learning is all the more pertinent in the current knowledge society, in which people engage in teamwork that is information- and technology-rich, and that this trend is likely to continue in the future (Johnson & Johnson 1996; Knight et al. 2006; Siemens 2008; Kang et al. 2010).

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[15] Vygotsky postulates a link and interchange between a student's learning and their development (physical/mental maturation).

Historically, it has been argued that the focus of traditional schooling on individual student abilities and knowledge actually inhibits effective learning by creating barriers to social learning (Scardamalia & Bereiter 1996), but in recent years there has been an increased willingness to consider collaborative learning in a school context (Dabbagh 2005; Knight et al. 2006; Tseng & Tsai 2007; Nicholas & Wan 2009; Slavin 2011; Bertacchini et al. 2012; Egger et al. 2012; Jenkins et al. 2012; Ryoo et al. 2013; Crick 2017; Waite 2017). In particular, collaborative learning has garnered research support in computer science education (Alonso et al. 2005; Nuutila et al. 2005; Beck & Chizhik 2008; Papanikolaou & Boubouka 2010; Egger et al. 2012; Jenkins et al. 2012; Melero et al. 2012; Ryoo et al. 2013; Waite 2017).

It is proposed that learning most naturally occurs not in isolation, but by students working together. Discussion allows them to share information, summarise points, verify and test their knowledge, and debate their opinions. It helps the student understand the views which they disagree with, and consider multiple perspectives when solving problems (Cunningham 1991; Lebow 1993; Dabbagh 2005). In addition, by focusing groups of students on the common objective of solving a problem, it gives them a common impetus to stimulate their learning and through the discussion, debate, contradiction and construction necessary in solving the problem, it arguably helps them reach their full potential (Roger & Johnson 1988; Dillenbourg et al. 1995; Johnson & Johnson 1996; Jonassen 1999; Vrasidas 2000; Nuutila et al. 2005; Williams et al. 2008).

In the computer science field, the terms *"cooperation"* and *"collaboration"* are often used to indicate a subtle difference; cooperation involves students' dividing and assigning tasks within the group to solve the problem, whereas collaboration involves a joint group endeavour to solve the problem (Dillenbourg et al. 1995). This pedagogy uses the term collaborative to cover both cooperative and collaborative learning; however, it should be noted that the typical focus is on collaborative learning (as defined previously).

Originally, Moore (1989) proposed three types of interaction in distance learning: student-teacher, student-student, student-content. This was followed by Hillman et al. (1994) who proposed a student-interface interaction. More recently, Dron (2007) proposed four additional types of interaction: group-content, group-group, learner-group, and teacher-group.

In relation to collaborative learning and social constructivism, this pedagogy focuses on the following interaction types: student-teacher, student-student, student-content, group-group, learner-group, and teacher-group. The overriding objective is that the collaborative learning environment (CLE) software will give learners access to shared information and the tools for learners to work collaboratively and to construct shared knowledge.

According to Slavin *"there is a fair consensus among researchers about the positive effects of cooperative learning on student achievement"* (2011, p.345)**.** However, not all research findings place the same value on collaborative/cooperative learning, the best circumstances to use it, and the most effective collaborative practices (Lou et al. 2001; Tutty & Klein 2008; Kirschner et al. 2009; Slavin 2011; Clark & Mayer 2011). Although, when used with appropriate preparation and support, and with a clear instructional goal, it can lead to educational benefits, such as: improved student achievement; improved long-term retention and higher-order thinking; and increased student motivation. Furthermore, according to Kirschner et al. (2009), where task/learning complexity is high, dividing the processing of information across students gives further benefit since it allows information to be distributed across a larger reservoir of cognitive capacity. But the inverse must also be considered, where the cognitive load exerted by the task/learning is low, the recombination and coordination inherent in collaborative learning cause an unnecessary overhead.

2.4.6 Connectivism

One of the most influential proponents of connectivism, George Siemens (2004; 2006; 2008), proposes that connectivism is a learning theory for the digital age, and positions it as a successor to existing theories. Siemens(2006) and Downes (2006) contend that existing learning theories are no longer adequate in the face of our improved understanding of learning, the increasing pace of knowledge growth, the ubiquity of technology, the unmet expectations of recent generations (Generation Y, Millennials, etc.), and the great complexification of knowledge.

Connectivism posits that learning can occur outside of people and that in fact learning is the network; citing Siemens and Downes forum responses, Kop and Hill (2008) summarise that the creation of connections between information nodes signifies knowledge, and that the ability to recognise patterns within complex networks, and to traverse these information nodes, comprises learning.

Despite Siemens' protestation that constructivism and social constructivism do not consider learning outside of people and that they are outdated, he sees a small measure of alignment with constructivism in that constructivist *"classrooms which emulate the "fuzziness" of this learning will be more effective in preparing learners for life-long learning"* (Siemens 2004, p.2). In addition, the closer link between connectivism and social constructivism is well-documented (McLoughlin & Lee 2008; Anderson 2008; Wang et al. 2014; Bell 2010; Siemens 2004).

Connectivism seems to intuitively reflect the realities of our digitally saturated world and the necessity of lifelong learning (typically, outside of formal institutions), and as such has a number of practitioners that support and adopt connectivist approaches (Couros 2009; Downes 2005; Chiong & Jovanovic 2012; McLoughlin & Lee 2008; Rochefort & Richmond 2011; Wang et al. 2014; Bessenyei 2008). Connectivists argue that the focus of existing learning theories does not satisfactorily reflect learning in today's interconnected world, and that there is an educational paradigm shift away from students being taught by teachers, typically in a classroom context. This paradigm shift is rooted in the new opportunities and challenges brought about by the exponential growth and complexity of information available on the internet, new possibilities for people to communicate on global networks, and the ability to aggregate different information streams.

Balancing popular support, there is academic debate on whether connectivism has the rigour to be a true learning theory, whether it is supported by an empirical body of evidence, and whether it replaces more established theories (Bell 2011; Kop & Hill 2008; Siemens 2006; Verhagen 2006). However, what is clear is that the contemplation of connectivism does add value in the development of new learning paradigms (Bell 2011; Kop & Hill 2008) and in particular, in the development of this pedagogy.

In accordance with Siemens (2004) the main principles of connectivism are as follows:

1. Learning and knowledge rests in diversity of opinions.
2. Learning is a process of connecting specialised nodes or information sources.
3. Learning may reside in non-human appliances.
4. Capacity to know more is more critical than what is currently known.
5. Nurturing and maintaining connections is needed to facilitate continual learning.
6. Ability to see connections between fields, ideas, and concepts is a core skill.
7. Currency (accurate, up-to-date knowledge) is the intent of all connectivist learning activities.
8. Decision-making is itself a learning process (i.e. choosing what to learn and its meaning in the current context).

Extreme connectivist positions as discussed by Kop and Hill (2008), Siemens (2008), and Bessenyei (2008) related to Illich's (1971) educational vision of de-schooling and *'community webs'* are not considered in the e-learning pedagogy. Instead, the previous eight principles are considered as the basis of the heuristics outlined in section 4.7.4.

2.4.7 VARK Learning Styles

Learning styles are a relatively new set of theories that propose that each of us have our own personal preferences on how we learn. These personal preferences relate to the best way in which we accept incoming information, process it and then demonstrate learning. Campbell et al. (1996) define learning styles as a certain specified pattern of behaviour according to which an individual approaches the learning experience. Likewise, Dunn et al. (1981) define learning styles as the way in which the individual takes in new information and develops new skills. Writing in the book Contemporary Theories of Learning (2009), Howard Gardner aligns with constructivist principles in advising that students are not an empty vessel to be filled with knowledge. Instead, due to their biological and cultural backgrounds, personal histories, and experiences, they possess different kinds of minds, with different strengths, interests, and modes of processing information. This initially complicates the teaching process and can lead to ineffectual teaching, but once considered and understood, it can actually lead to more productive teaching that reaches more students on a deeper level.

Research from psychology and education spanning over four decades support the overall proposition of learning styles. This research has in turn spawned a wide range of inventories which try to define and assess the various learning style dimensions (e.g., Canfield & Lafferty, 1974; Dunn, Dunn, & Price, 1987; Honey & Mumford, 1982; Kolb, 1984). In their widely-cited critical review of learning styles, Coffield et al.

(2004) identify 71 models of learning styles, and expound that it is a growing body of research that is still producing ideas and a proliferation of instruments.

The widespread and popular appeal of learning styles amongst educators in schools and higher education stems from the simple recognition that not all students respond equally well to the same instructional approaches, and that at face value, learning styles provide a tool for educators and their students to better align on what works best (Dunn et al. 1981; Frank Coffield et al. 2004; Weiler 2005; Fleming & Baume 2006; Franklin 2006; Leite et al. 2010; Popescu 2010; Newton 2015). However, in spite of the appeal and widespread use of learning styles, it remains a complex and often disputed area of education research, split between those who:

1. acknowledge the research debate, but offer broad support to learning styles (Dunn et al. 1981; Weiler 2005; Fleming & Baume 2006; McCartney et al. 2007; Illeris 2009; Othman & Amiruddin 2010; Popescu 2010);
2. offer a balanced critical analysis of shortcomings and applicable use of learning styles (Johnson & Johnson 1996; Klein 2003; Frank. Coffield et al. 2004; Frank Coffield et al. 2004; Clark & Mayer 2011; Fleming 2012);
3. explore the complexity of the research area, in terms of varying research quality, multiple inventories and their instrument validity, and find a relative lack of robust empirical evidence towards learning benefits (Johnson & Johnson 1996; Frank Coffield et al. 2004; Fleming & Baume 2006; Kirschner et al. 2006; Leite et al. 2010; Popescu 2010; Clark & Mayer 2011; Fleming 2012); and
4. offer perspective pieces that aggressively challenge the educational value and use of learning styles, branding them as a *‘neuromyth’* (Franklin 2006; Newton 2015).

This pedagogy concentrates on one of the better known and well used learning style models; Neil Fleming’s VARK model focuses on the preferred mode of perceiving information within a learning context. In recent years, Fleming and Baume (2006) and Fleming (2012) have clarified that the VARK model does not constitute a full learning styles model in that it focuses only on the students’ and educators’ preferred modes of communication, and does not address a wider set of learning behaviours and preferences.

The VARK model is based on four perceptual modes: Visual (V), Aural (A), Read-Write (R) and Kinaesthetic (K). According to Fleming and Baume (2006), Othman & Amiruddin (2010) and Fleming (2012), the VARK Model is based on the original VAK sensory modalities. Fleming and Baume (2006, p.5) explain that “*some students had a distinct preference for the written word whilst others preferred symbolic information as in maps, diagrams, and charts.*” Since these two preferences are not always aligned in the same person, a second '*visual*' modality for read-write learners was introduced in VARK. The VARK modalities are outlined below:

1. Visual (V) - Visual learners prefer graphical and symbolic ways of representing information.
2. Aural (A) - Auditory learners prefer to learn from listening.

3. Read-Write (R) - Read-Write learners prefer to learn through information displayed as words.
4. Kinaesthetic (K) - Kinaesthetic learners prefer learning that connects them to experience and reality.

According to Allen et al. (2011) the VARK model has three basic principles:

1. Each person can learn, but may do so differently, irrespective of their level or ability.
2. Student motivation increases when their learning preferences are accommodated.
3. It is better to present new material using the learner's preferred mode of perception.

The students' preferred learning style(s) are identified by a short multiple-choice questionnaire that places them in several situations within their experience and asks them to specify their preferred action(s); this in turn indicates their favoured modal preference(s) (V, A, R, K). For each question, the respondent can select one or more options, or can even omit questions where they find no suitable option.

As discussed earlier, the research on learning styles contains some debate on whether a focus on learning styles leads to genuine educational benefits and, if such a focus is to be taken, what the best implementation is. Hence, once the students' modal preferences are identified, different educational strategies can be employed. At a high-level, there are two broad approaches: adaptive or multi-modal.

In the adaptive (matching) approach, the curricula and pedagogy are tailored to the different modal preferences of the students, thereby increasing their motivation and learning performance. However, the complexity and effort involved in implementing such an approach should not be underestimated; providing individualised curricula and pedagogy for several high school classes, managing the varying performance, whilst still providing meaningful feedback is incredibly challenging. From the outset, Fleming (1992, p.138) the author of VARK, acknowledges this challenge and advises "*it is simply not realistic to expect teachers to provide programs that accommodate the learning style diversity present in their classes.*" Coffield et al. (2004) also reassert the point that the large scale adoption of matching instruction towards individual learning styles is unrealistic given the demands it would place on teachers and trainers.

It is, though, posited that current and future technologies can greatly support this process by catering to the different modal preferences (Zapalska & Brozik 2006; Condie & Munro 2007; Gardner 2009; Popescu 2010). Advanced e-learning software that uses data analytics to build student profiles can in turn use artificial intelligence approaches to offer different entry points and individualised educational experiences based on affective status, past performance and modal preferences (TSIRIGA & VIRVOU 2004; Virvou et al. 2005; Brusilovsky & Millán 2007; Schiaffino et al. 2008). However, Coffield et al. again prescribe caution:

"It should be noted that the potential of ICT to support individualised instruction has not been fully evaluated. However, the key point is that individualised instruction is not likely to work if it means more unsupported individual learning." (Frank Coffield et al. 2004, p.133)

It is argued that the biggest danger with the adaptation (matching) approach, and one of the largest sources of contention in learning styles research, is the potential for pigeon-holing or stereotyping learners, which ultimately damages their learning and development (Dunn et al. 1981; Klein 2003; Frank Coffield et al. 2004; Franklin 2006; Condie & Munro 2007; Pritchard 2009; Fleming 2012; Newton 2015). Prevailing research opinion is that learning styles should be considered indicative, not diagnostic, and considered in relation to the learning context and content, not rigidly tailored to specific student learning styles.

In order to counter such problems, the majority of learning style theorists (Dunn et al. 1981; Felder & Silverman 1988; Fleming & Mills 1992; Honey & Mumford 2000; Klein 2003; Frank Coffield et al. 2004; Fleming & Baume 2006; Zapalska & Brozik 2006; Pritchard 2009; Leite et al. 2010; Birch et al. 2011; Fleming 2012) promote the idea that learners should develop a repertoire of styles, so that an awareness of their own preferences and abilities should not bar them from working to acquire those styles which they do not yet possess. A person can have multiple dominant modal preferences, and in any case, the less favoured modal channels should not be ignored. Instead the more encompassing approach is to use the learning styles classification as a self-reflection tool, by which both teachers and students can understand their own natural tendencies and, armed with that knowledge, actively manage their teaching and learning.

It is typical for teachers to teach according to their preferred modal channel, not their students. It follows that this needs to be broadened to provide learning experiences that accommodate all modal preferences. Likewise, e-learning software should be developed to accommodate all modal preferences. The multi-modal approach thereby combines a mixture of approaches and teaching methods that support all modal preferences. The students' improved self-awareness then allows them to actively choose the instructional style that best fits their individual modal preference. This pedagogy therefore focuses on the multi-modal approach.

2.4.8 ARCS Theory of Motivation

As discussed in section 2.4.2, learning requires significant mental effort; therefore, students need to be suitably motivated to devote the mental energy to learn. There is a significant body of research recognising that motivation is as an important factor and precursor to learning (J. Keller 1987; J. M. Keller 1987a; J. M. Keller 1987b; Hidi & Harackiewicz 2000; Illeris 2003; Alonso et al. 2005; Palmer 2005; Long 2007; Anderson 2008; Cook et al. 2009; Shroff & Vogel 2009; Hadjerrouit 2010; Ejiwale 2012; Herman 2012; Kim et al. 2014; Royal Society 2017a).

Motivation is a characteristic inherent within each learner, but must be fostered and enhanced by the learning material and instructional design of the lesson (Cook et al. 2009). Its impact on learning is complex and underpinned by a multifaceted interplay of factors such as: the students' level of self-efficacy and self-regulation; situational and individual interest; extrinsic and intrinsic motivation; and performance and mastery goals, etc. (Schunk 1991; Hidi & Harackiewicz 2000; Lepper et al. 2005; Palmer 2005;

Anderman & Dawson 2011). Lepper et al. (2005) maintain that there is over a half a century of research into intrinsic motivation and its impact on learning, but assert with concern that:

"The lower levels of intrinsic motivation for older versus younger children reported here are troubling. Not only do children seem to be losing their enjoyment of the learning process itself but the systems of extrinsic incentives and constraints that American schools employ to keep students on track do not effectively compensate for the declines in intrinsic motivation." (2005, p.193)

In contrast, e-Learning and technology-enhanced learning are often viewed as inherently motivational, arguably in many instances due to temporary novelty value; but in addition, they also offer motivational affordances that can help make learning more engaging. However, Keller & Suzuki (2004) warn it is important that these motivational affordances are considered deeply within the instructional design of the e-learning, otherwise it still runs the danger of being a novelty to learners that quickly loses its appeal. Furthermore, there are counteractive motivational forces to be considered since despite the popularity and global growth of e-learning and online learning delivery (Elaine & Seaman 2011; ATD Research 2014; Ambient Insight Research 2015; ATD Research 2017), there remains historic challenges in stimulating and maintaining learner motivation in e-learning, and in particular in distance learning (Zvacek 1991; Rowntree 1992; Visser 1998); this is most evident in the high drop-out rates in independent distance learning (Lee & Choi 2011; Levy 2007; Liyanagunawardena et al. 2013). This in turn has led to a significant volume of research into the importance of learner motivation in e-learning, as well as the technological affordances and pedagogical theory that support it (Phipps & Merisotis 2000; Huffaker & Calvert 2003; Keller & Suzuki 2004; Virvou et al. 2005; Ardito et al. 2006; Connolly & Stanfield 2006; Condie & Munro 2007; Boulton 2008; Zhang & Bonk 2008; Hsu et al. 2009; Jang 2009; Papastergiou 2009; Shen et al. 2009; Zaharias & Poylymenakou 2009; Alsumait & Al-Osaimi 2010; Corbalan et al. 2010; Jung 2011; Lee & Choi 2011; Liu et al. 2011; Muntean 2011; Stuchlikova & Benkovska 2011; Bertacchini et al. 2012; Fletcher et al. 2012; Livingstone 2012; de Freitas & de Freitas 2013; Morrison & DiSalvo 2014).

In particular, this pedagogy focuses on John Keller's ARCS model (1987a; 1987b; 2008; 2006). For many years, Keller has been developing and testing a systematic process for analysing learner motivation and designing motivational techniques focused on the following areas: Attention, Relevance, Confidence and Satisfaction (ARCS). Keller (1987a), defines the ARCS categories as:

1. **Attention:** Capturing the interest of learners; stimulating the curiosity to learn,
2. **Relevance:** Meeting the personal needs/goals of the learner to affect a positive attitude,
3. **Confidence:** Helping the learners believe / feel that they will succeed and control their success,
4. **Satisfaction:** Reinforcing accomplishment with rewards (internal and external).

The ARCS model is based on a comprehensive review and synthesis of motivational research; its conceptual validity has been confirmed in several research papers (Visser & Keller 1990; Small & Gluck 1994; Means et al. 1997), and it has been successfully applied and validated in e-learning instruction

(Chyung et al. 1999; Song & Keller 2001; Cook et al. 2009; Lim et al. 2009; Zaharias & Poylymenakou 2009; Corbalan et al. 2010; Yacob et al. 2012).

2.4.9 Cognitive Load Theory

Cognitive Load Theory (CLT) considers the human cognitive architecture and processes, and their inherent limitations, in explaining how incoming information from eyes and ears are transformed into knowledge and skills in human memory (Sweller et al. 1998). There is well established support for the consideration of cognitive load in: instruction, computer science instruction, and e-learning (Moreno 2004; Mehlenbacher et al. 2005; Kester et al. 2006; Kirschner et al. 2006; Harskamp et al. 2007; Anderson 2008; Tutty & Klein 2008; Lim et al. 2009; Hadjerrouit 2010; Clark & Mayer 2011; Morrison et al. 2014) and a wide body of research on approaches to reduce and optimise cognitive load (Sweller et al. 1998; Pollock et al. 2002; Kalyuga & Ayres 2003; Klein 2003; Mayer & Moreno 2003; Moreno 2004; Sweller 2004; Kester et al. 2006; Kirschner et al. 2006; Harskamp et al. 2007; Moreno & Mayer 2007; Fadel & Lemke 2008; Kirschner et al. 2009). As outlined by Clark and Mayer (2011) CLT proposes that learners do not passively receive incoming information, but instead undertake active cognitive processes that take in relevant information, organise it into logical structures, and integrate it with existing knowledge for long term recall. CLT is based on three main principles:

1. **Dual Channels** - Humans have separate channels for processing visual and auditory material.
2. **Limited Mental Capacity** – At any given time humans can actively process only limited information in each channel; material that exceeds this threshold may enter working memory but will not be processed and encoded into long term memory.
3. **Active Processing** – Human learning occurs when the appropriate cognitive processes are engaged to mentally organise incoming auditory and visual sensory information and integrate it with existing knowledge so that it can be stored in and recalled from long term memory.

The above principles and learning process are represented in Figure 6.

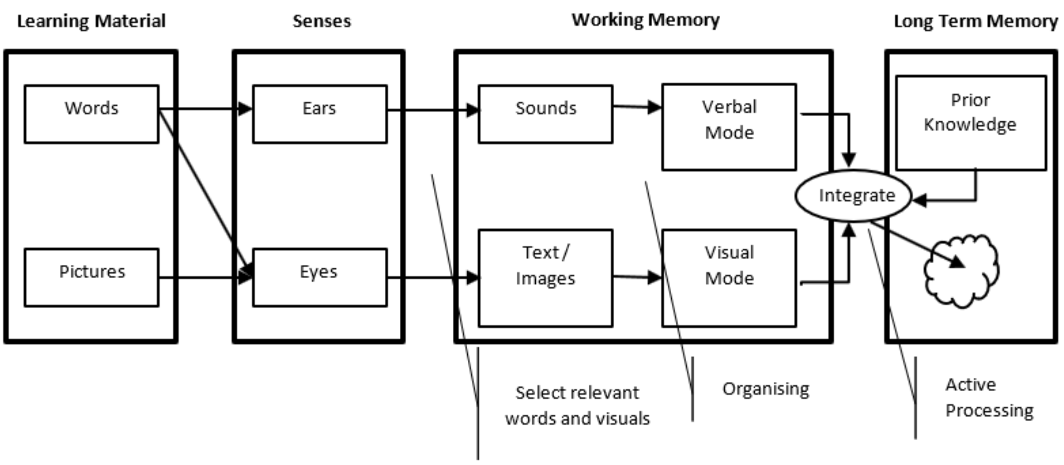

Figure 6: Cognitive theory of learning
Adapted from (Mayer & Johnson 2008, p.381)

This model of learning leads to three types of cognitive processing.

1. **Essential (intrinsic) processing** is the processing of the core learning material, and is dependent on the inherent complexity of the material. The correct application of guidance, scaffolding and segmenting of learning material can support it.
2. **Extraneous processing** is processing that does not support the instructional objectives and is created by poor instructional design and the inclusion of irrelevant or duplicate learning material.
3. **Generative (Germane) processing** is processing aimed at the development of new schemas or integration into existing schemas, and the automation of these schemas. It is aimed at deeper understanding (and far transfer) of the core material by motivating the learner to make sense of the material and integrate it into their schemas so that it can be recalled and applied in the appropriate circumstance.

Considering CLT, an appropriate instructional strategy is therefore to:

1. Support the learner in selecting the important information in the lesson (signposting).
2. Support the learner in managing the limited capacity of working memory by:
    a. Minimising extraneous cognitive load by a careful focus on the core learning material.
    b. Optimising essential processing by the careful management of the complexity of the core learning material.
3. Maximise generative cognitive processing by providing an opportunity for non-trivial practice activities, guided instruction, and authentic (relevant) examples and problems. This enables integration into existing schemas, and the hooks to allow for retrieval at a later stage.

CLT's positive impact on learning performance (retention) is well established; however, it is also contended that judicious use of Cognitive Load approaches improve germane processing, hence deep learning and far transfer (Sweller et al. 1998; Mayer et al. 2001; Moreno & Mayer 2002; Mayer & Moreno 2003; Mayer et al. 2003; Moreno 2004; Moreno & Mayer 2005; Harskamp et al. 2007; Moreno & Mayer 2007; Mayer & Griffith 2008; Mayer & Johnson 2008; Rourke & Sweller 2009; Skudder & Luxton-Reilly 2014).

In many respects constructivism and CLT model the same learning processes, but from differing perspectives. Both focus on the active construction of knowledge and skills as schemas. But constructivism focuses on principles of authenticity and active learning and how new learning is assimilated or accommodated in schemas. Whereas, CLT takes an information processing perspective and focuses on the efficiency of the learning process and the different types of memory used during learning. In spite of their potential similarities, it is well recognised that there lies a tension between constructivist principles and CLT (Kirschner et al. 2006; Anderson 2008; Alonso et al. 2009; Vogel-Walcutt et al. 2011), in particular between discovery-based learning (Problem-Based Learning) and CLT (Sweller & Cooper 1985; Sweller et al. 1998; Moreno 2004; Sweller 2004; Moreno & Mayer 2005; Schraw et al. 2006; Moreno & Mayer 2007; Lim et al. 2009). This is addressed in the proposed pedagogy and the underlying formulation of heuristics, by focusing on moderate constructivist approaches, explanatory feedback and scaffolding, and guided discovery[16].

In relation to collaborative learning, Kirschner et al. (2009, p.31) argue that "*learning by an individual becomes less effective and efficient than learning by a group of individuals as task complexity increases*." Therefore, where learning material is intrinsically complex and demanding, then collaborative learning may be appropriate since it "*allows information to be divided across a larger reservoir of cognitive capacity*". The inherent complexity of the learning material must be carefully considered since for less complex learning the coordination, recombination and collaborative learning processes add an unnecessary cognitive overhead. Irrespective of this, the use of collaborative learning must always be structured, appropriately prepared, and guided to reduce extraneous cognitive processing.

In relation to multi-modal learning, CLT's dual channel principle offers partial support for multi-modal learning via visual and aural channels; however, full multi-modal learning via all four VARK modalities is considered to create a high extraneous cognitive load.

In relation to learner motivation, Keller and Suzuki (2004) cite research from Chang and Lehman (2001) in asserting that motivational approaches, in particular related to the relevance dimension, can be aligned with CLT; however, it should be noted that unrestrained motivational approaches can negatively impact cognitive load.

Overall, a central theme within the pedagogy is that the use of pedagogical heuristics in all other areas must be considered in light of their potential impact on cognitive load.

A final consideration within CLT is the prior knowledge and expertise of the learner (i.e. existing schemas); several of the approaches within CLT support low-knowledge learners, but may not support or may even impede high-knowledge learners. This is called the expertise reversal effect (Pollock et al. 2002; Kalyuga & Ayres 2003; Sweller 2004; Kalyuga 2005; Harskamp et al. 2007; Lim et al. 2009). This considers that the level of CLT support must be tailored to the level of expertise of the learner and should typically be gradually faded.

2.4.10 Gamification

According to Deterding et al., gamification is "*the use of game design elements in non-game contexts*" (2011, p.9); in this case the context is education. Gamification does not focus on creating fully fledged games, but instead uses game dynamics, mechanics, and frameworks to increase pleasure, fun, motivation, and to influence behaviour. In the context of this research, it is to increase student motivation and ultimately to increase learning performance.

[16] As oppose to pure discovery-based learning.

Gamification has been a trending topic in recent years with significant commercial interest and usage, and a significant growth in academic papers (Deterding et al. 2011; Deterding 2012; IVETIC & Petrović 2012; Deterding et al. 2013; Hamari et al. 2014; Morrison & DiSalvo 2014; Iosup & Epema 2014; Pirker et al. 2014). Despite the growing number of papers published on gamification, there remains a lack of clarity on what the gaming affordances proposed in gamification are and how to effectively design a gameful system (Deterding et al. 2013; Deterding et al. 2011). Based on a significant literature review, and meta-analysis of 24 empirical studies, Hamari et al. (2014) suggest that the most common gaming affordances are points, leaderboards, achievements/badges, levels, stories, clear goals, feedback, rewards, progress and challenge. These are taken as the basis of the gamification heuristics proposed in this research. Additionally, Hamari et al. (2014), and various other studies (Papastergiou 2009; Deterding et al. 2011; Deterding 2012; Nicholson 2012; IVETIC & Petrović 2012; Decker & Lawley 2013; Deterding et al. 2013; Stott & Neustaedter 2013; Haaranen et al. 2014; Iosup & Epema 2014; Morrison & DiSalvo 2014; Pirker et al. 2014), suggest that the empirical evidence for gamification is mixed, although overall is positive.

Gamification has significant potential, but unfortunately, suffers from a tarnished reputation; all too often, the complexity of well-designed games are simply reduced to their more superficial elements (Stott & Neustaedter 2013). Deterding argues that the current stock implementation of gamification focuses on the least important parts of games, such as points, badges and leaderboards, and adds them to mundane user activities (2012). As quoted by Deterding, Elizabeth Lawley, a professor of interactive games and media, counsels that when a comprehensive set of gaming affordances are considered and implemented properly, "*gamification can help enrich educational experiences in a way that students will recognize and respond to*" (2012, p.17). Based on their analysis, Stott and Neustaedter go one step further and advise that "*the underlying dynamics that make games engaging are largely already recognized and utilized in modern pedagogical practices, although under different designations*" (2013, p.1). This point is recognised in this research, ensuring the integration of a comprehensive set of game affordances into the proposed pedagogical heuristics.

2.4.11 Computational Thinking

Jeannette Wing, one of the key proponents of computational thinking (CT), defined computational thinking as involving *"solving problems, designing systems, and understanding human behaviour, by drawing on the concepts fundamental to computer science"* (2006b, p.33). In 2011, she further clarified that computational thinking is "*the thought processes involved in formulating problems and their solutions so that the solutions are represented in a form that can be effectively carried out by an information-processing agent*." (Cuny, Snyder, Wing, 2010, cited in, Wing 2011, p.60). It is important to note that the term information-processing agent does not necessarily mean a computer system; computational thinking does not inherently lead to computer solutions. It is more focused on reformulating seemingly difficult real-world problems that are complex, messy and partially defined into a form that is tractable and can be solved (Wing 2006b; Wing 2006a; Barr & Stephenson 2011; Lee et al. 2011; Zhou 2011; Grover & Pea 2013; Curzon et al. 2014). It does this by borrowing concepts and mental tools from computer science such as abstraction, generalisation, iteration, recursion, decompositions, modelling, automation and algorithms. The aim is not to get humans to think like computers, but to marry the rigour and transparency of computing techniques with the ingenuity, imagination and creativity of humans. In recent years, computational thinking has gained momentum and received significant publicity (Wing 2006b; Wing 2006a; Guzdial 2008; Barr & Stephenson 2011; Wing 2011; Gouws et al. 2013; Grover & Pea 2013; Curzon et al. 2014; Lye & Koh 2014; Selby et al. 2014).

Wing argues that computational thinking will be a fundamental skill used by everybody by the middle of the 21st Century, and that it should be added to every child's analytical ability in the same way as reading, writing and arithmetic. This opinion is being taken seriously and computational thinking is being integrated into the national curriculum of several nations. For example, in the UK (Brown et al. 2014):

"A high-quality computing education equips pupils to use computational thinking and creativity to understand and change the world." (DfE 2013, p.151)

In the United States:

"the approach to problem-solving generally described as CT is a recognizable and crucial omission from the expertise that children are expected to develop through routine K–12 Science and Math education (although CT has finally been mentioned, albeit briefly, in the 2012 NRC K–12 Science Education framework)." (Grover & Pea 2013, p.4)

It is argued that use of computers and computational thinking have revolutionised research and innovation in science, engineering and other disciplines. The Royal Society gives a number of examples of where computational thinking is radically influencing other disciplines: the Human Genome Project, the Large Hadron Collider, predicting global climate change, analysing the spread and control of infectious diseases, the Airbus fly-by-wire system, and the pharmaceutical sector (The Royal Society 2012).

However, there needs to be some caution since there remains a variety of academic and pedagogic interpretations of what computational thinking is, what differentiates it from other thinking skills, how best to teach it, and what can realistically be expected from our children (Guzdial 2008; Hazzan et al. 2008; Barr & Stephenson 2011; Lee et al. 2011; Wing 2011; Grover & Pea 2013; Selby & Woollard 2013; Curzon et al. 2014; Lye & Koh 2014; Selby et al. 2014). This lack of a consistent and coherent definition is causing some negative repercussions since the misleading message propagated by popular media and received by parents and teachers is that computational thinking equates with coding (Selby et al. 2014). Another area of concern is that currently there is not a wealth of empirical evidence to link computational thinking to improved problem-solving or far transfer to other problem domains. Hemmendinger (2010) notes that perhaps computer scientists are, to some extent, guilty of arrogance and overreaching in that many of the elements claimed to be part of computational thinking have been around for a while, and are not within the sole domain of computer science. The pedagogical heuristics proposed in this research will not focus on these academic debates, but instead concentrate on the elements of computational thinking proposed by the UK Department for Education (DfE), AQA, EDEXCEL and OCR award bodies, and the barefoot computing initiative.

3 RESEARCH METHODS

3.1 Chapter Brief

This chapter first outlines foundation concepts in research design and methodologies, and discusses the underlying rationale for the three-phase mixed methods approach (section 3.2). The remainder of the chapter then describes the research design used in this study, specifically:

1. The three-phase mixed methods research design,
2. The procedures used in each phase and cycle of the study,
3. The controls put in place to ensure validity, reliability and trustworthiness,
4. The teacher, student and education expert participants used in each phase and cycle of the study,
5. The instruments and materials used in each phase and cycle of the study,
6. The data collection, analysis and reporting used in each phase and cycle of the study, and
7. The research methods used in the development of the e-learning evaluation protocol.

3.2 Theoretical Foundations of the Research Design

The aim of this study is to synthesise a holistic pedagogy for the design and evaluation of e-learning software for high-school computing, and then to test its impact on student learning and motivation. In keeping with this aim, the initial focus of the research was on the exploration of learning theories and their synthesis into an e-learning pedagogy, followed by a quantifiable assessment of the pedagogy's impact on student learning and motivation. Based on these prerequisites, the study was designed with three phases, in which each phase used a mixed methods approach, but with a different qualitative-quantitative mix. With reference to relevant literature, the following sub-sections discuss the underlying theoretical rationale for the three-phase mixed methods approach.

3.2.1 Research Paradigm

Each research study falls within a paradigm continuum ranging between the two extremes of positivism (quantitative) and interpretivism (qualitative). A central tenet of quantitative research is the objective (unbiased) reporting of a single reality, whilst qualitative research views that there is no single reality, but instead each person has their perception of reality (Lincoln & Guba 1985; Guba & Lincoln 1989; Field & Hole 2003; Creswell 2007; Creswell & Plano Clark 2010; MacKenzie 2013). Qualitative research embraces the view that each participant has their own interpreted reality, and the possibility that the researcher's own interpretation may colour the research findings. It accounts for this by actively communicating the sets of beliefs, basic assumptions, way of thinking, and framework that inform the conduct and writing of the research study. Creswell (2007; 2010) defines this as the underlying paradigm or worldview that governs the research; he characterises it in accordance with the following worldview elements: ontology, epistemology, axiology, methodology, and rhetoric. The specific stance that this research takes for each worldview element is outlined in Table 5.

Worldview Element	Research Stance
Ontology What is the nature of reality?	Singular and multiple realities are considered; primarily a single reality, but in some cases viewed through multiple perspectives.
Epistemology What is the relationship between the researcher and that being researched?	In Phase 1 and 2, a prolonged engagement is used to build a close relationship with participants, but professional impartiality is used to collect data from participants (participants are not treated as full collaborators). In Phase 3, a short engagement is planned with an increased focus on impartiality and objectivity.
Axiology What is the role of values?	Depending on the research phase and the nature of the data (qualitative or quantitative), there are multiple stances used; meaning the inclusion of potentially biased and unbiased perspectives.
Methodology What is the process of research?	Both quantitative and qualitative data are collected and combined.
Rhetoric What is the language of research?	Typically, the style of writing is more formal in nature, more aligned with a quantitative study; it avoids the typical qualitative writing style based on thick first-person literary descriptions. However, the voice of the participants is carried through in the wide use of direct quotes. Qualitative and quantitative terminology is used appropriately.

Table 5: The Worldview underlying this research study

In keeping with Creswell and Plano Clark's (2010) description of four high-level worldviews: post-positivist, constructivist, participatory, and pragmatist, this research study is broadly aligned with the pragmatist worldview. Pragmatism is a philosophy oriented towards "*what works*" in practice (Creswell & Plano Clark 2010) and is commonly associated with mixed methods research (Yvonne Feilzer 2010; Creswell & Plano Clark 2010). According to Johnson and Onwuegbuzie (2004) citing Dewey (1948), it focuses on practical consequences and real-world phenomena and problems. It can take many forms since pragmatists insist on the freedom to choose the methods, techniques and procedures most appropriate to the problem under study and the research needs (Johnson & Onwuegbuzie 2004).

3.2.2 What is Mixed Methods Methodology and Why was it Used?

This study combined elements of qualitative and quantitative research approaches into a mixed methods research design. Creswell and Plano Clark (2010) give a comprehensive definition of what mixed methods is: "*as a methodology, it involves philosophical assumptions that guide the direction of the collection and analysis and the mixture of qualitative and quantitative approaches in many phases of the research process. As a method, it focuses on collecting, analysing, and mixing both quantitative and qualitative data in a single study or series of studies. Its central premise is that the use of quantitative and qualitative approaches, in combination, provides a better understanding of research problems than either approach alone*." (2010, p.4)

Mixed methods is particularly suited to this study since it provides compelling support for studies in which: exploratory findings need to be generalised; results need to be explained; results need to be triangulated to increase validity; and one data source is insufficient to give a complete picture (Creswell & Plano Clark 2010; Johnson & Onwuegbuzie 2004).

Inherently, the use of both qualitative and quantitative research methods provides a more comprehensive understanding of the problem domain. This was particularly relevant in the first two research phases of this study, which were exploratory in nature, and in which both qualitative and quantitative methods provided a detailed understanding of how the pedagogical heuristics (embodied in the prototype software) performed within a school context.

The results of one method were used to elaborate, illustrate or clarify the results of the other method. As discussed in later sections, this research used observation studies, survey instruments and focus groups in which the observation study and the survey instrument were used to inform the focus group; and often qualitative data from the survey instrument and focus group were used to explain or illustrate quantitative data from the observation study or survey instrument.

Furthermore, the use of both approaches offset the weaknesses of one with the strengths of the other. Arguably, the reductionist nature of quantitative research is weak in representing the full richness of the problem domain and in understanding its context. Furthermore, it lacks depth by not linking back to the voice of the participants (Creswell & Plano Clark 2010). In this research, the focus groups and survey instruments where used to good effect in identifying the underlying opinion and voice of the student participants. In contrast, qualitative research is arguably flawed due to the personal interpretations made by the researcher, the potential for bias created by this, and the difficulty in generalising to a larger population (Field & Hole 2003; Creswell & Plano Clark 2010; Lazar et al. 2010). The issue of potential researcher bias is mitigated by marrying quantitative results with qualitative findings and ensuring they are aligned.

It is also important to note that qualitative and quantitative approaches are best suited to answering different research questions; for example, qualitative methods are best suited to the development of theory, such as the pedagogical heuristics in this study, whilst quantitative methods are more suitable for adding an additional confirmation and potentially generalising the findings (Creswell & Plano Clark 2010; Field 2013). Hence, Phase 3 was designed specifically to confirm the exploratory phases and generalise the findings to the wider student population.

Additionally, by combining both qualitative and quantitative views, this research could focus on questions that could not be answered by either approach individually; more specifically, when the qualitative and quantitative views did not concur it guided further research to understand why. This was particularly significant in the exploratory phases of this research since further investigation in later phases or cycles was prompted where the qualitative and quantitative views diverged.

A further reason to use mixed methods is that results from the different methods can be triangulated to corroborate each other, which in turn leads to results that are considered to have greater validity (Bryman

2006; Borrego et al. 2009). Hence, the qualitative and quantitative findings from the observation studies, focus groups, survey instruments and other research instruments were triangulated to gain a comprehensive and valid set of results.

Additionally, it is common practice to use qualitative research to inform the instrument development for a later quantitative phase (Creswell & Plano Clark 2010). This approach was used in this research by the iterative improvement of the survey instrument and e-learning prototype for final use in Phase 3.

One final benefit of mixed methods research is that it is *'practical'* in nature; it allows the researcher the freedom to use all methods possible to address the research problem (Creswell & Plano Clark 2010; Yvonne Feilzer 2010; Johnson & Onwuegbuzie 2004).

However, the use of mixed methods is not without its drawbacks. Johnson and Onwuegbuzie (2004), and Creswell and Plano Clark (2010) outline some key challenges, such as: the researcher is required to have skills in both qualitative and quantitative approaches, and how to mix them effectively; the use of mixed methods can demand extensive time, resources, and effort from the researcher; and there still remains a potential for philosophical objections or a lack of understanding of the value of mixed methods from the research audience. The first two points have been challenges faced in this study; in particular, the increased demand on time, resources and effort have been significant factors.

3.2.3 The High-level Structure of the Mixed Methods Design

Creswell and Plano Clark (2010) build upon various seminal works to provide a primer on how to align a mixed methods design with specific research objectives. For example: whether the research design will be fixed or emergent; choosing a particular mixed methods design; and determining the timing, level of interaction, and priority of quantitative and qualitative strands within a research phase.

Fixed and/or Emergent - As with many research designs, this study falls between being a fixed and an emergent design. It was fixed since the three phases were predetermined and planned at the start of the research process, and the research methods within each phase were implemented largely as planned. However, it was also emergent since the details of the design of the second and third phases emerged based on the findings of the previous phases.

Exploratory Sequential Design - The overall phased approach utilised an exploratory mixed methods design; the exploratory design was based on sequential phases of qualitative theory development followed by a final phase of quantitative research to test the theory on a different and larger sample. As typified by theory development exploratory design, the initial qualitative phases took priority (Morgan, 1998; Morse, 1991). Due to the shift in paradigms between phases, the worldview within the research shifted from a more interpretist worldview in Phases 1 and 2 towards post-positivism in Phase 3.

Convergent Parallel Design - Each phase of the study followed a mixed methods convergent parallel design, otherwise known as a triangulation design. As outlined by Morse, the purpose of the convergent design is *"to obtain different but complementary data on the same topic"* (1991, p. 122) to better understand the research topic. The qualitative and quantitative data were collected mainly concurrently, but separately. In Phase 1 and 2 the weight of qualitative data was more than the quantitative data, hence it was given priority; this trend was reversed in Phase 3. The two data sets were collected and analysed separately and independently from each other, using typical quantitative and qualitative procedures. After the data were analysed, the results were merged and interpreted to identify to what extent and in what ways the two sets of results converge, diverge or relate to each other. This approach enabled the corroboration between the two types of data, and therefore increased the inherent validity of findings.

Figure 7 summarises the above, showing the exploratory sequential design, based on sequential phases of qualitative theory development (i.e. the pedagogical heuristics) followed by a final phase of quantitative research to test the theory on a different and larger sample.

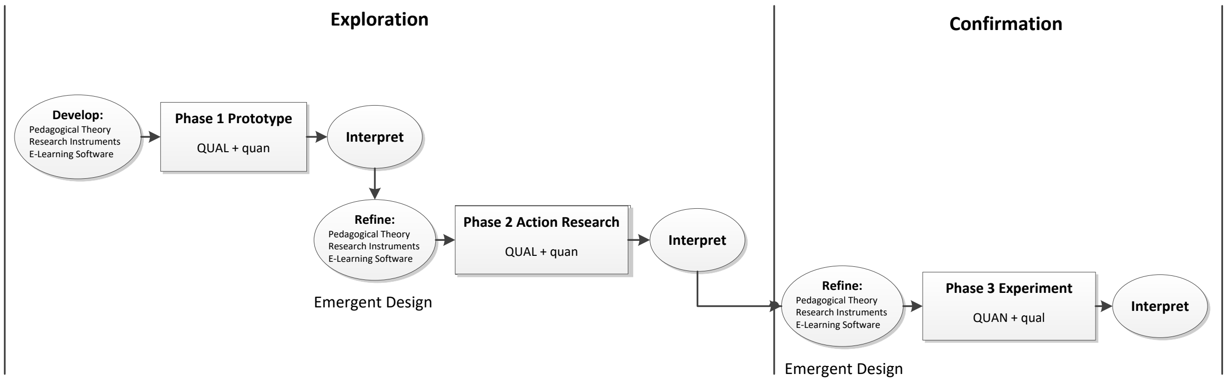

Figure 7: The high-level structure of the phased research

The findings from the convergent parallel design used in each phase informed the refinement of the pedagogical heuristics, research instruments, and e-learning software tool used in the next phase. Finally, at the end of Phase 3, the quantitative and qualitative strands were combined in a final interpretation activity to discuss and draw final research conclusions.

3.2.4 Validity, Reliability and Trustworthiness

The differences and philosophical debate on what constitutes validity in quantitative and qualitative research is widely and passionately discussed in research literature (Maxwell 1992; Golafshani 2003; Morse & Barrett 2008; Guba & Lincoln 2005; Borrego et al. 2009; Guba & Lincoln 1989; Creswell 2007; Creswell & Plano Clark 2010; Lincoln & Guba 1985), but is beyond the scope of this study. This research aligns with the direction set by Lincoln and Guba (1985) in their seminal work Naturalist Inquiry. It is argued that whilst quantitative research focuses on internal validity, external validity, reliability, and objectivity, these criteria are less suitable for qualitative research due to the fundamental paradigmatic differences between the two approaches. Instead, a set of parallel criteria focused on trustworthiness are discussed for qualitative research; these are credibility, transferability, dependability and confirmability.

Where the research had a quantitative priority, the validation strategies used were associated with Internal Validity, External Validity (generalisable), Reliability and Objectivity (Field & Hole 2003; Lazar et al. 2010; MacKenzie 2013).

1. **Internal Validity** refers to the extent to which the experimental effect observed is due to the test conditions; it attempts to protect the experiment results from being corrupted by some other unintended factor. In the context of this research, it means that the Phase 3 experiment accurately measures student learning and identifies whether the pedagogical design of the e-learning software influenced learning and/or motivation. Most importantly, this should be achieved without any undue influence on the dependent variable (learning) by some other confounding factor.
2. **External Validity (Generalisable)** refers to the extent to which the experiment results can be generalised to other people and other situations (i.e. a wider population). In the context of this research, it means that the results have a wider use beyond the sample to infer results to the overall GCSE Computer Science population.
3. **Reliability** refers to the consistency, stability and predictability of the research over time. It is a prerequisite for validity since unreliable research methods cannot lead to valid research results. Reliability ensures that an experiment is replicable and can be reproduced and confirmed as accurate multiple times.
4. **Objectivity** refers to how the research is protected from value or bias; it is typically achieved by the utilisation of methods and instruments that mitigate the possibility of human bias distorting quantitative results.

Where the research had a qualitative priority, the validation strategies used were associated with credibility, transferability, dependability and confirmability.

1. **Credibility** attempts to establish that the constructed realities of the research participants, and the realities represented by the researcher and attributed to these participants match (Guba & Lincoln 1989; Creswell 2007). In relation to this research, this means that the feedback on the pedagogy collected from the research participants is accurately understood and reflected by the researcher.
2. **Transferability** - The small sample size means that the findings from Phase 1 and 2 cannot be considered generalisable to a wider population; however, they can be considered transferable to a similar context. The important point is that the description necessary to identify that context is provided to enable another researcher interested in making a transfer to reach a conclusion about whether it is possible (Lincoln & Guba 1985).
3. **Dependability** is parallel to the quantitative concept of reliability and focuses on the consistency, stability and predictability of the research and qualitative data over time (Creswell 2007; Lincoln & Guba 1985). However, it is important to note that this excludes intentional methodological changes brought about by an emergent design. Guba and Lincoln (1989, p.242) maintain that methodological changes "*need to be both tracked and trackable (publicly inspectable), so that outside reviewers of such an evaluation can explore the process, judge the decisions that were made, and understand what salient factors in the context led the evaluator to the decisions and interpretations made.*"

4. **Confirmability** is parallel to the quantitative concept of objectivity and confirms that the data, interpretations, and outcomes of the inquiry are based on the contexts and participants of the inquiry, and not biased or inventions of the researcher. According to Guba and Lincoln (1989) this means that research data can be tracked to its source and that the logic used to reach subsequent interpretations is transparent, coherent and corroborated by source data.

3.2.4.1 Validity and Reliability of the Survey Instrument Design

Due to the importance of survey instruments in almost all fields of research (Litwin 1995; Krosnick 1999; Creswell & Plano Clark 2010; Lazar et al. 2010; Saris & Gallhofer 2014), it is worthwhile briefly reviewing some of the concepts used to establish validity and reliability in survey instrument design. This is particularly relevant in this study due to the central thread the survey instrument plays in all phases.

Unfortunately, according to (Litwin 1995; Krosnick 1999; Lazar et al. 2010; Saris & Gallhofer 2014) the design and testing of a valid and reliable survey instrument is no trivial task. It is for this reason that an initial step is to try to identify an existing, established instrument that is pre-validated, and that has a good fit with the study in question (Litwin 1995; Lazar et al. 2010).

If no such instrument exists, then a new survey instrument must be designed specifically for the study. Considering (Litwin 1995; Krosnick 1999; Creswell & Plano Clark 2010; Lazar et al. 2010; Saris & Gallhofer 2014), to ensure unbiased, good quality data, the design of the survey instrument should consider aspects such as: pilot testing, test-retest (intra-observer) reliability, alternate form reliability, internal reliability, inter-observer reliability, face validity, content validity, criterion validity, and construct validity. As discussed in sections 6.2.3.1 and 6.2.4.1, this study focuses on (as defined by Litwin (1995)):

1. **Pilot testing (pretesting)** – One of the most important steps in the development of a new survey instrument is to test the instrument with a smaller sample to identify unanticipated issues in the instrument's form, delivery and analysis. This includes, but is not limited to: instrument delivery; instrument structure, such as length, numbering, skip flow, etc.; item language, spelling, grammar and respondent appropriateness; and data coding and analysis.
2. **Test-retest reliability** – This establishes how reproducible the survey instrument's data are; it can be achieved by having the same respondents complete the survey (or survey item) at two different points and seeing how consistent the responses are.
3. **Alternate form reliability** – This tries to mitigate the practice effect, by which respondents become familiar with survey items and respond based on memory; it can be achieved by using differently worded items to measure the same attribute.
4. **Internal consistency reliability** - To increase reliability, multiple survey items can be used to measure different aspects of the same concept. However, it is critical that these items do accurately measure the same underlying concept; hence the consistency of their measurement must be ascertained.

5. **Face Validity** - The most basic review of validity is typically a cursory review of the survey instrument by untrained individuals. As a weak validity measure, this is typically skipped in favour of content validity.
6. **Content Validity** – Focuses on how well the survey instrument measures the constructs it sets out to measure; it is carried out by reviewers who have knowledge or expertise in the subject matter.

Inter-observer reliability, criterion validity and construct validity are not addressed directly in this study and hence, for brevity, are not discussed in this brief review.

3.2.5 Action Research Design

Within the overarching mixed methods design, Phase 2 follows an action research design. O'Brien(2001) describes action research in simple terms: it is *"learning by doing"* – a group of people identify a problem, think about how to fix it, take some action to fix it, see how successful they were, and, if not satisfied, try again. Put in such terms, it gives the impression that action research lacks rigour; this is not the case Susman and Evered (1978) detail a five-phase cyclical process, which forms the basis of the action research cycle used in this research:

1. Diagnosing,
2. Action Planning,
3. Action Taking,
4. Evaluating, and
5. Specifying Learning.

It is also important to note that action research is not just about problem-solving; to remain valid as research a theoretical foundation must be present as the basis of the intervention action. According to Baskerville and Wood-Harper (1996), action research is a well-established, practice-based approach that merges research and praxis, thus producing especially relevant research findings. Levy (2003) outlines the concept of praxis as being informed, committed action that gives rise to knowledge rather than just successful action. The reference to *"informed"* means it is a social collaborative activity that involves the significant contribution of the research participants. The reference to *"committed"* means it is a planned and intentional action. And finally, the objectives of action research go beyond a successful local action, but must also result in the generation of new knowledge. In the context of this research, the new knowledge is the definition and elaboration of pedagogical heuristics for e-learning. This is aligned with the long history of action research in educational research; in particular, McNiff and Whitehead (2005) argue that action research has much to offer in the generation of quality educational theory.

Additionally, mixed methods and action research fit well together; a meta-analysis of 108 Mixed Methods Action Research (MMAR) studies between 1999 and 2012 showed that 35% were in education (Ivankova 2014). Ivankova (2014) argues that mixed methods provide a sound and pragmatic research approach to support action research, and in particular provide a solid scientific methodological framework for it.

Although action research is often viewed as a qualitative reflective approach, there is a growing body of literature discussing the compatibility and harmonious use of mixed methods and action research (Hinchey 2008; Mills 2011; Koshy et al. 2011; James et al. 2007).

Specifically, Mills (2011) asserts that mixed methods can be used to good effect in educational action research when researchers need to enhance observations and qualitative narratives with quantitative student performance data. In addition, Greenwood and Levin (2007) argue that action researchers need to be knowledgeable of quantitative and qualitative data collection strategies in order to address complex social problems (such as learning).

It should be noted that when deciding to follow an action research design, there was an internal deliberation (which is not entirely resolved) on whether this research was more allied with action research or design-based research. There is significant commonality and overlap between the two methods; design-based research shares many characteristics with action research, in that: it is practice-based; focused on real-world settings; follows iterative cycles; has a strong background in education research; and is often used to extract shareable theories (The Design-Based Research Collective 2003; David 2007; Barab & Squire 2004; Sandoval & Bell 2004; Wang & Hannafin 2005). However, arguably, design-based research has a stronger focus on design principles and the development of an educational environment or artefact; whereas in this research, the e-learning software is used purely as a prototype test tool. This study does not dogmatically follow action research since, in action research, the research topic typically has a local origin, and the research is often driven by the study participants, one of which is typically the principal researcher. In this research, the research objectives have a strong local resonance, but did not originate in the schools used in the study; additionally, whilst there was a strong collaborative relationship, ultimately the study was governed by a researcher external to the research locations. In this respect this study was more aligned with design-based research (Pardo-ballester & Rodríguez 2009; Wang & Hannafin 2005). In a final analysis, action research was chosen due to its comparative maturity, the rigour it adds to the research design, the relative richness of research that documents the steps to use in action research, and its extensively cited usage with mixed methods.

3.2.6 Incremental and Iterative Development Methodology

As previously outlined, an e-learning software prototype was developed to embody the e-learning heuristics in a tangible form for student usage, testing and learning. An incremental and iterative development model (Larman & Basili 2003; Cockburn 2008; Ruparelia 2010) was used to design and develop the e-learning software across the three phases of the research. As summarised by Cockburn (2008):

1. **Incremental Development**: focuses on delineating different parts of the e-learning software which are developed at different times or rates and integrated as they are completed. Within each phase/cycle of the study and the associated releases of the e-learning prototype, different aspects of the computer science curriculum, heuristics and parts of the software prototype were focused on. This is discussed in more detail in sections 6.2.2 and Figure 30 (section 6.5)

2. **Iterative Development:** based on previous evaluation cycles, iterative development was used to revise and improve the different parts of the e-learning prototype. The evaluation cycles gathered student feedback on the e-learning prototype to improve the heuristics, but this was also fed back into the design/development process to improve the next version of the software prototype.

Based on this methodology, the different versions of the e-learning software prototype are outlined in section 6.2.2, and the student feedback based on the various versions of the software are reported in sections 6.5 and 6.6. Figure 8, visually represents the incremental and iterative development process.

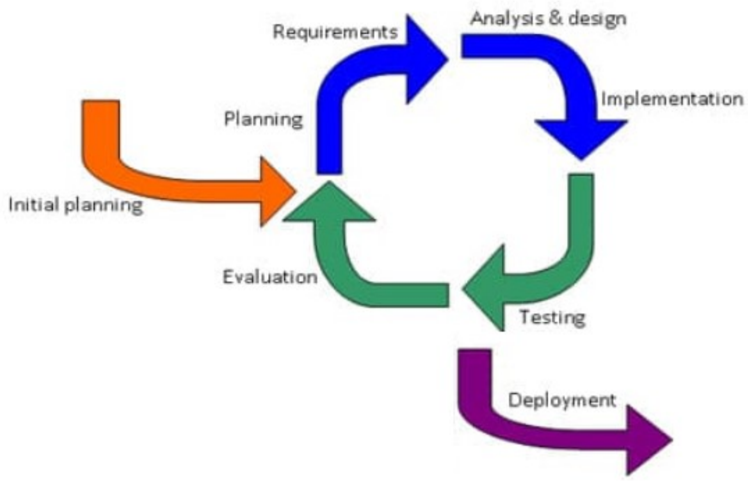

Figure 8: The incremental and iterative development model.

Adapted from (Ghahrai 2018)

For each phase/cycle the planning stage identified at a high-level what educational content (parts of computer science curriculum) and pedagogical heuristics were to be included; this planning scope was then specified in terms of requirements.

In keeping with standard design practice for educational software, before each development iteration these requirements were analysed and transformed into a detailed design which combined the pedagogical heuristics and the educational material, to represent them in a mixture of images and text in the storyboard documents. The storyboards documented a clear description of the instructional design, educational content and presentation before committing to software development.

During the implementation stage a combination of Captivate 8 (e-learning), Visual Studio 12 Web (Web and XML) and Photoshop CS6 were used to develop SCORM 2004 (3rd Edition) compliant e-learning software.

Prior to student usage of the e-learning software during the observation study, the researcher tested the prototype software according to the following 3-step test approach:

1. Unit testing on the development environment using multiple web-browsers.
2. End-to-end testing of the cloud-hosted version of the software using multiple web-browsers.

3. End-to-end testing of the cloud-hosted version of the software using multiple web-browsers, from within the school's computer lab.

As discussed in sections 2.3.2 and 2.3.3, it is important to reiterate that usability is a mandatory pre-requisite for e-learning software. Although this study has purposely taken a restricted focus towards pedagogy, usability was taken into consideration in the development of the e-learning software. After Phase 1 an external expert usability evaluation was carried out, and this feedback was incorporated into Phase 2. In parallel, a professional graphical designer provided their services to ensure the Graphical User Interface (GUI) had a baseline of aesthetic appeal and more importantly consistency across graphical elements. This approach ensured a foundation of usability that would not detract away from the pedagogical aspects of the e-learning software.

3.3 Introducing the Three Phases of Research

Building upon section 3.2.3, this study is divided into three phases; Phase 1 and Phase 2 have a qualitative priority. Phase 1 acted as a pilot study and Phase 2 employed action research methods in two cycles of study. The rationale for the first two phases was to initially work in-depth, using a significant literature review and involving a smaller number of students, teachers and education experts to inform the synthesis of the pedagogical heuristics. This approach iteratively and progressively refined the heuristics and e-learning software test tool.

Phase 3 had a quantitative priority, involving a larger student sample, to identify the impact of the heuristics (as embodied in the e-learning software test tool) on student learning and motivation, and to generalise the study findings to the wider student population. This research design is represented diagrammatically in Figure 9.

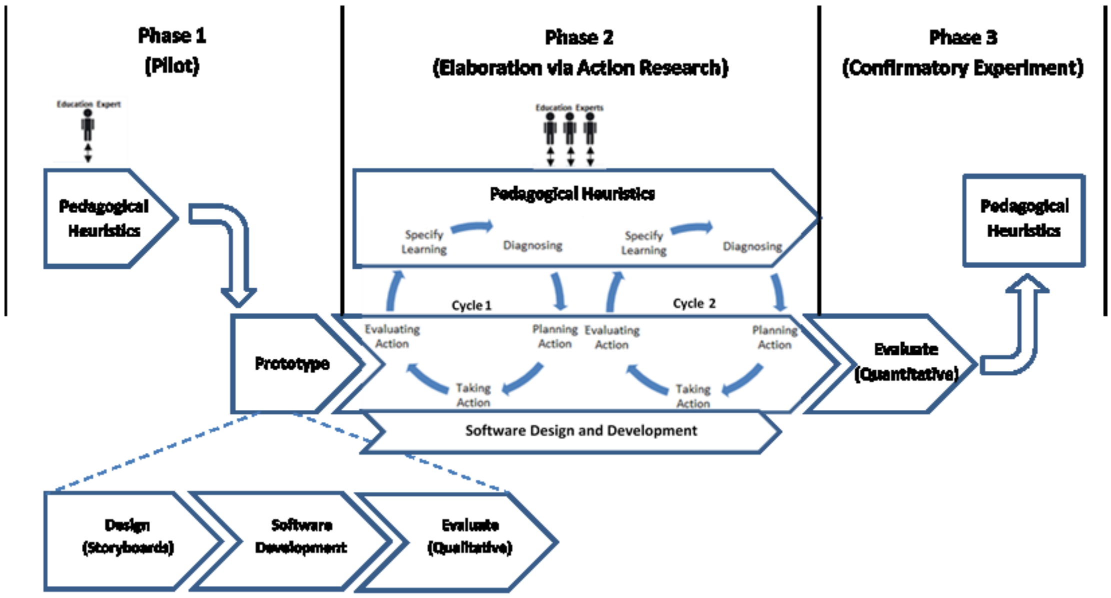

Figure 9: The three phases of research.

As an initial orientation, Table 6 provides a high-level summary of the instruments and instrumentation[17] used in this research, their primary purpose, the data type of information collected, and the phase(s) they were used in.

Instrument / Instrumentation	Purpose	Phases	Data Types
Pedagogy Evaluation Feedback Document	Used to collect feedback from education experts and teachers on the pedagogical heuristics. Where necessary, this was followed by one-to-one interviews to clarify feedback.	2 &3	Qualitative feedback - Open text Quantitative ratings -Interval data
VARK Learning Styles Instrument	A survey instrument used to Identify student modality preferences.	1,2, & 3	Quantitative categorisation – Nominal data
E-learning Software Prototype	An iteratively refined software test tool used to embody the e-learning heuristics into a tangible form for student usage, testing and learning.	1, 2, & 3	Quantitative – Usage metrics from the Learning Management System (LMS).
Observation Study	Observation of student usage of the e-learning software prototype. The observation study was documented informally in handwritten notes and transcribed later after the observation.	1 & 2	Qualitative Observation notes
Survey Instrument	An iteratively refined survey instrument used in all phases to collect student rating and opinion on the e-learning software prototype. Feedback was then extrapolated towards the pedagogical heuristics.	1, 2, & 3	Quantitative rating – Interval data Qualitative opinion – Open text
Focus Group	Informed by the observation study and survey results in each phase and used to collect in-depth qualitative feedback from the students on the e-learning software prototype. Feedback was then extrapolated towards the pedagogical heuristics.	1 & 2	Qualitative opinion – Video recording
Pre-Test / Post-Test	A GCSE Computer Science test used to measure student learning performance before and after using the e-learning software.	3	Quantitative – Ratio data

Table 6: Summary of main research instruments and instrumentation used in the study

The remainder of this chapter discusses:

1. The three phases of the research, specifically their objectives, participants and research activities;

[17] The use or application of instruments (as for observation, measurement, or control) (Merriam-Webster 2018b).

2. Data collection, analysis and reporting; and
3. The procedures and controls put in place to satisfy the validity, reliability and trustworthiness of the study.

3.4 Phase 1: Pilot Study

3.4.1 Objectives

The primary objective of Phase 1 was to set a strong foundation for the research study; this was achieved in terms of:

1. Piloting the research methods and protocol,
2. Developing the first draft of the pedagogical heuristics, and
3. Developing a working e-learning software prototype, which was in turn used for evaluation purposes.

3.4.2 Phase 1 Participants

3.4.2.1 Exploratory Phases: Student Participant Overview

The participants for each phase of the study are discussed in the relevant sections. However, before discussing Phase 1 and Phase 2, it is important to note that these two phases have a qualitative priority; therefore, a small sample[18] of GCSE students (15/16 years old) from a local private school in Cyprus was chosen. Participant recruitment was undertaken via a presentation to both the students and their guardians, accompanied by information letters and consent forms.

The sample size is the same for both the qualitative and quantitative strands of these phases; this aids correlation, but does not allow for statistically significant research results. This is not a concern since this is not an objective of these phases.

Using the same participants in the qualitative and quantitative strands of research is recommended by Creswell and Plano Clark (2010), who advise that when the purpose is to corroborate, directly compare, or relate two sets of findings about a topic, the individuals who participate in the qualitative sample should be the same as those who participate in the quantitative sample.

Ideally, in such a study, purposeful sampling would be undertaken in which participants are intentionally selected due to their inherent capacity to contribute to the understanding of the research problem; specifically, a combination of Maximum Variation and Typical Case sampling would be optimal. However, due to constraints on appropriate student participants in the research location (Cyprus), all research participants were taken from two GCSE ICT classes in the 1st (year-4) and 2nd year (year-5) of the GCSE. It

[18] Eight students were originally recruited; however, the number of participants varied depending on the phase and research activity. This is discussed in more detail in the relevant sections.

is important to note that since the students were taken from a private school, they are all high-performers; based on mock exam results for GCSE ICT, all the year-5 students were A* students, and based on internal school exams, the three year-4 students had two A grades and a B grade. It should also be noted that although unavoidable, the recruitment of GCSE ICT students may not fully represent GCSE Computing students; furthermore, the ICT GCSE syllabus does not cover in detail algorithms and computational thinking[19]. Overall, this means that student responses may not be fully representative of the GCSE Computer Science population. This point is partially mitigated by the fact that Phase 1 and Phase 2 do not measure learning performance, and do not aim for statistically significant research results. The qualitative student feedback on the e-learning software and the underlying pedagogy remains valuable, but has some limitations on its transferability to the wider GCSE population.

3.4.2.1.1 Phase 1 Students

The recruitment process secured eight students to participate in Phase 1; these participants were taken from the 1st year GCSE ICT class (year-4). As discussed in the previous section, all students were high performers. The initial recruitment process established the Phase 1 student sample; however, thereafter attendance was voluntary and based on student availability: eight students attended the observation study, seven of those students responded to the survey, and six of those students attended the focus group.

3.4.2.2 Teachers and Educational Experts

Five education experts were involved in the evaluation of the pedagogical heuristics in Phase 1, all of whom were senior university academics in the fields of child computing interaction, computer science, education and educational media, and curriculum, pedagogy and assessment.

One GCSE ICT teacher, with an educational background in computer science and over five years of teaching experience, also provided evaluation feedback on the pedagogical heuristics.

3.4.3 Pilot of Research Methods

As part of good research practice (MacKenzie 2013), it is important to undertake pilot testing to get an early assessment of the research methods, experiment protocols and data collection and analysis approaches to be used. As a pilot stage, Phase 1 allowed the early identification of limitations in the:

1. Research methods,
2. Participant selection,
3. Survey instrument,
4. Observation protocols,
    a. Participant instructions,

[19] The fact that the ICT GCSE syllabus does not cover in detail algorithms and computational thinking is positive since it avoids unintentional influence on student opinion from ongoing learning within the GCSE.

   b. Participant training,
   c. Experiment preparation,
   d. Environment and technical checks,
   e. Researcher behaviour (professional neutrality), and the
5. E-learning software design and development processes.

The feedback and lessons learnt in this area were incorporated into the research methods and experiment protocols of later phases, and are documented in section 6.3.1

3.4.4 Phase 1 Research Activities

The Phase 1 research is broken down into the following activities.

1. Literature review of learning theories.
2. Research on GCSE Computer Science curriculum – focus on algorithms.
3. Synthesis of pedagogical heuristics into an e-learning pedagogy.
4. Evaluation of pedagogical heuristics from teacher and education experts (refer to section 6.2.1).
5. Design of e-learning Software – Storyboards (refer to section 3.2.6).
6. Develop and test e-learning software prototype (refer to section 3.2.6).
7. Secure ethics approval for research in schools.
8. Secure informed consent from head-teacher, teachers, students and parents.
9. Distribute VARK learning styles instrument (refer to section 3.4.4.3).
10. School-based observation of student usage of e-learning software prototype (refer to section 3.4.4.4).
11. Distribute survey instrument (refer to section 3.4.4.5).
12. Undertake focus group (refer to sections 3.4.4.6).
13. Merge and interpret results from different research strands.
14. Provide feedback back to participants (member checking) to verify that researcher interpretation is correct.

A mixed methods procedural diagram is shown in Figure 10, which gives a visual representation of points 4 and 9 to 13.

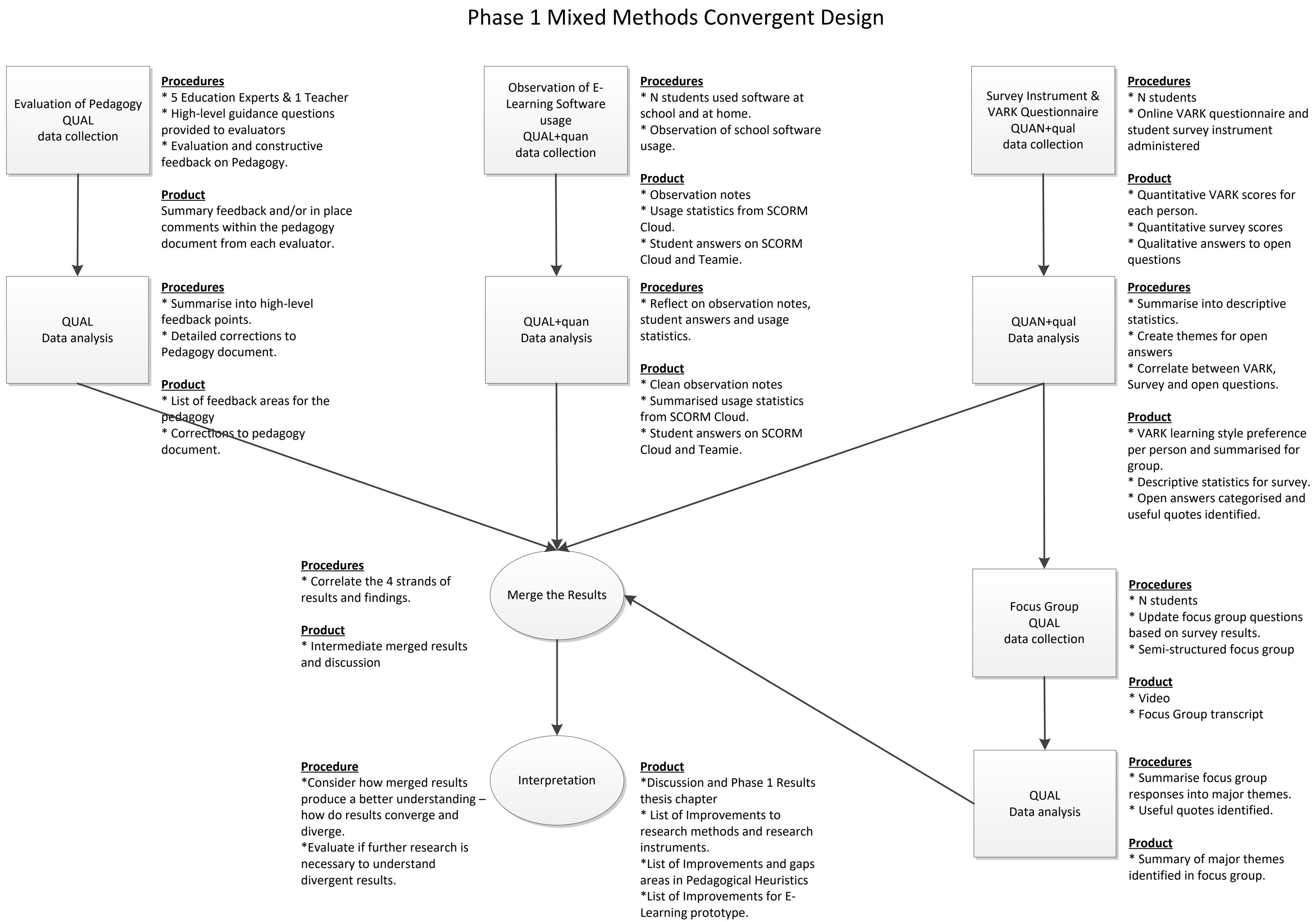

Figure 10: Phase 1 - mixed methods convergent design

3.4.4.1 Synthesis of Pedagogical Heuristics into an E-learning Pedagogy

The first step in Phase 1 was to undertake a comprehensive literature review resulting in the initial e-learning pedagogical heuristics for GCSE Computing. The literature review is outlined in section 2.4 and the synthesis of the e-learning pedagogy is discussed in Chapter Four.

3.4.4.2 Evaluation of Pedagogical Heuristics from Teacher and Education Experts

A central component of this research was the involvement of teachers and education experts in the evaluation and feedback on the e-learning pedagogy. The composition of the pedagogy evaluation group in Phase1 is outlined in section 3.4.2.2. The evaluator feedback was guided by the following factors:

1. Appropriateness of principles for 15/16-year olds,
2. Appropriateness of principles for computer science,
3. Feasibility of principles for teaching in schools,
4. Gaps in coverage, or weak areas that need to be improved,
5. Suggestions of best practice in implementing the principles,
6. Principles that you may disagree with altogether, and
7. New principles that are not considered in the current version of pedagogy.

Evaluators were given up to two months to review the e-learning pedagogy document, and feedback was provided in writing either by email and/or inline comments and corrections within the document. Where the feedback was unclear to the researcher, then one-to-one interviews were used to clarify.

The evaluation feedback was analysed and incorporated into the research at the start of Phase 2. This pedagogical feedback is summarised in section 6.4.1.

3.4.4.3 Distribution of the VARK Learning Styles Instrument

The VARK learning styles instrument was used in Phase 1 to collect data on students' preferred modalities. The instrument was administered to the student participants before the observation study; it was distributed via email to the participants' research email accounts. The emails contained a link to an online survey tool by which the survey was administered. Pseudonyms (protecting anonymity) were used throughout the process, from distribution all the way to interpretation of results.

Data from this instrument was collated automatically via the online survey tool, and exported in comma-separated value (CSV) format. This was then imported into a spreadsheet program to categorise each student's response according to the Visual, Aural, Read-Write and Kinaesthetic modalities. Each student's VARK profile was then summed to show the overall modal preferences of the group.

This approach for distribution, data collection, and analysis was unchanged between Phase 1 through to Phase 3.

Further information about the VARK learning styles instrument is outlined in section 6.2.3

3.4.4.4 Observation Study

After the first e-learning software prototype was developed (refer to section 6.2.2.1), an observation study was organised by the researcher to observe student usage. This was organised on school premises in the school's ICT lab; the observation started at 13:30, after the students had completed their school day and had time for a short break. Ten minutes were allocated to an introduction and organising the participants; then the student participants used the e-learning software prototype for a period of 1 hour and 10 minutes, allowing the research investigator to observe the direct usage of the software. The researcher provided minimal guidance and support (e.g. forgotten login credentials, resuming an e-learning session if prematurely exited, slow connectivity and video streaming issues etc.).

At the end of the observation, the students were asked to progress and complete the remaining sections of the e-learning software asynchronously from home.

Throughout the observation, no research instrument was used. However, prior to the observation, a suggested environment checklist (refer to section 6.2.5) was distributed by email for the student participants to check their home environment and for the school to check their ICT lab for compatibility.

Notes from this observation study were documented informally by the researcher in handwritten notes and transcribed later after the observation.

The student answers posted onto the SCORMCloud platform and Teamie collaborative learning environment were reviewed for: correctness, whether they were attempted, the number of attempts and, where available, the duration taken to answer.

High-level usage patterns were also collected from the SCORMCloud platform showing the number of accesses and the duration of each access to the learning material.

This information was then correlated and reflected upon to identify any major themes that required further investigation in the focus group.

3.4.4.5 Distribution of Student Survey Instrument

After the observation study, but before the focus group, a student survey instrument was administered to student participants to collect feedback on their use of the e-learning software prototype. The online survey instrument was distributed according to the same controls and procedures as the VARK learning styles instrument.

Data from this instrument was collated automatically via the online survey tool, and exported in comma-separated value (CSV) format. This was then imported into a spreadsheet program for further analysis, and summarised in descriptive statistics and bar charts showing student feedback frequencies. The responses to open questions were thematically grouped and evaluated in terms of their value as quotable comments. A preliminary analysis of the student responses was used to inform the questions in the focus group.

Further information about the student survey instrument is discussed in section 6.2.4

3.4.4.6 Focus Group

After the Phase 1 observation study, a focus group was held in which student participants had a facilitated discussion where they elaborated on the key themes identified in the observation study and the survey results. The focus group was loosely guided by a PowerPoint presentation that showed each e-learning screen and listed (visible only to the facilitator) a set of pertinent questions identified during the observation study, and the survey results. The presentation and questions were not used verbatim; instead, the screens were used to quickly refresh the memory of the participants, and key questions were used based on the flow and progress of the focus group.

The focus group duration was 75 minutes and was facilitated by the researcher in the school's ICT Lab. On this day the projector was not available to show the screens of the e-learning software prototype; however, paper screen prints were used for this purpose. The focus group was recorded on video and later transcribed into a summary format that gave significant detail, but did not transcribe word for word everything that was said. Student participants are visible in the video but are not referred to by name; the transcript only refers to pseudonyms. The original video is kept for archive purposes, but is encrypted in a separate network location.

The focus group transcript was analysed thematically to identify any key themes raised in the discussion, and evaluated in terms of the value of student responses as quotable comments.

3.4.5 Interpretation

The findings from the e-learning pedagogy review, observation study, VARK learning styles instrument, student survey instrument and focus group were examined holistically to understand whether the different research strands converged or diverged, to identify areas requiring further investigation and areas that gave direction to Phase 2.

The feedback to the research methods is summarised in section 6.3, and the teacher / expert feedback on the e-learning pedagogy are reported in summary form in 6.4.1, and elaborated thematically in full form in Vol 2 Appendix A.

Since Phase 1 and Phase 2 are exploratory phases, the findings from student usage of the e-learning software prototype are merged and reported together. These findings are reported in summarised form in section 6.5, and in full form in Vol 2 Appendix B; they consolidate the mixed methods strands (observation, survey and focus group) into a single picture. The findings are predominantly qualitative in nature, have a small sample size, and are a collection of open and ordinal data (Likert and Ranking); therefore, a statistical analysis, including significance tests, could not be carried out. However, descriptive statistics are presented in Vol 2 Appendix B; the descriptive statistics give a basic quantification of results in the form of bar charts of student feedback frequencies. These are then followed by textual descriptions that link to open responses from either the questionnaire or focus group, and interpret the result findings.

3.4.6 Phase 1 – Ensuring Validity and Trustworthiness

The basis of the pedagogical heuristics on well-established learning theories, with a wide pedigree of supporting research, gives them a strong foundation and means their appropriateness is likely. However, this is not enough; additionally, the involvement of an experienced teacher and education experts in evaluating the heuristics encourages their further refinement, and gives an additional verification of their suitability for computer science and the GCSE age group. Finally, student feedback of the e-learning test tool gives further feedback as to the fitness of the heuristics for GCSE Computing.

Since Phase 1 has a qualitative priority, the validation strategies used for the aforementioned inquiry are associated with trustworthiness; meaning a focus on credibility, transferability, dependability and confirmability. These validation strategies were discussed in general terms in 3.2.4. Before discussing how these strategies were employed in Phase 1, it should be noted that closely related to the discussion of the trustworthiness of Phase 1 research methods are the sections discussing the reliability and validity of the research instruments used (refer to sections 6.2.3.1 and 6.2.4.1).

Creswell (2007) suggests that of eight commonly used procedures to establish trustworthiness, qualitative researchers should employ at least two. In Phase 1 of the research three of the procedures are used: triangulation, member checks, and preparing for an inquiry audit.

3.4.6.1 Credibility

A key approach towards establishing the credibility of research findings is the triangulation of multiple and different sources (Creswell 2007; Lincoln & Guba 1985). This is a central approach within Phase 1 since findings from the observation study, the survey instrument and the focus group are all combined to form a single picture.

Additionally, a second fundamental approach towards establishing the credibility of research is the use of member checks. In qualitative terms, this is the process of verifying hypotheses, data, themes, and interpretations with the research participants that provided them (Creswell 2007; Guba & Lincoln 1989).

This approach was implemented informally by regularly summarising and representing back to the participants the researcher's understanding during that interaction, typically during the observation study and the focus group.

This was implemented more formally by officially presenting back to the research participants the findings attributed to them, and requesting their confirmation that it is a true account. In Phase 1, this was originally planned to be accomplished by a presentation of research findings back to the research participants. Unfortunately, the restricted availability of participants meant this was accomplished by distributing a report of the findings, which were commented on or confirmed by the participants.

3.4.6.2 Transferability

As discussed previously in section 3.4.2.1, transferability is limited to some extent by the use of high-performing students from a private school. However, in general, Phase 1 remains quite transferable since:

1. ICT GCSE level students were used for the research,
2. The research was carried out in typical learning environments; i.e. in an undisturbed ICT school lab, and later completed in the student's home environment,
3. All material, instruments and protocols are available for reuse, and
4. The participant feedback is relatively unambiguous and unlikely to be tainted by a biased researcher account.

3.4.6.3 Dependability and Confirmability

One approach to secure dependability and confirmability is the inquiry audit (Creswell 2007; Lincoln & Guba 1985); this is conceptually similar to a fiscal audit, and allows for an external auditor to examine both the process and products of the inquiry to assess whether the findings, interpretations, and conclusions are accurate and supported by the underlying data.

The researcher will not explicitly request an inquiry audit for this research, but the research was performed according to detailed methods and a rigorous approach to data collection, data analysis, and report writing that would facilitate an inquiry audit if one was requested by the supervisory team or the university.

Lincoln and Guba (1985) align with Halpern's (1983) research on inquiry audits, and suggest six audit trail categories; these are used in this research, partially in Phase 1 since it was a pilot study, and more rigorously in Phase 2. These categories are:

1. Raw data.
2. Data reduction and analysis products.
3. Data reconstruction and synthesis products.
4. Process notes.
5. Materials relating to intentions and dispositions.
6. Instrument development information.

3.5 Phase 2: Elaboration via Action Research

3.5.1 Objectives

The objective of Phase 2 was to build on the findings from Phase 1, and to further refine and elaborate the e-learning pedagogy and prototype software via an action research methodology. An action research approach was chosen since it links theory and practice, achieving both practical and research objectives (Susman 1983). The practical focus lies in the iterative development of the e-learning software and the research focus on the elaboration and evaluation of the pedagogical heuristics.

3.5.2 Action Research Cycle

As outlined previously in section 3.2.5, action research follows a cyclical five-stage process; the specific implementation of this study is represented in Figure 11.

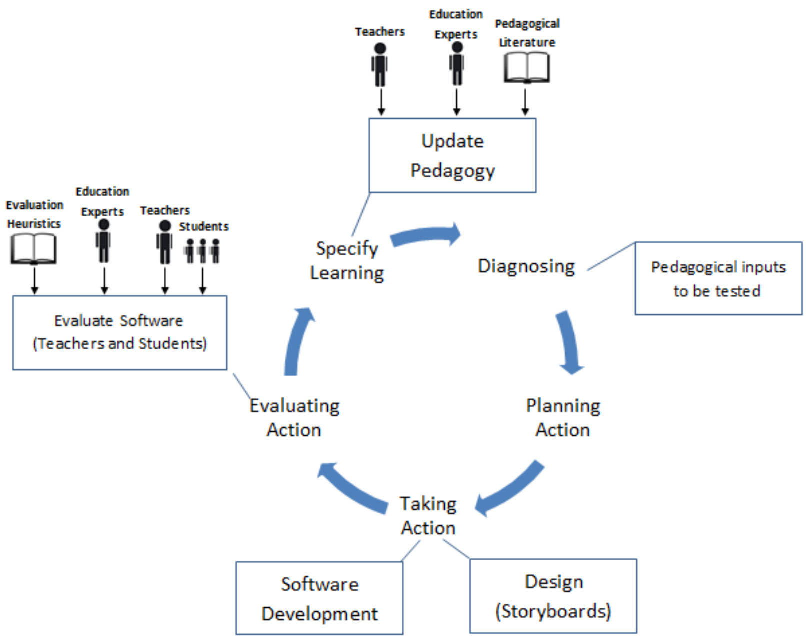

Figure 11: Action research cycle

Two cycles of evaluation and update were included in this phase. A small number of GCSE Computing teachers and students were recruited from local high-schools to evaluate the e-learning software and the underlying pedagogy. With each cycle of action research, the e-learning pedagogy was updated based on the constructive input of experienced teachers, education experts and ongoing literature review. Then, aspects of the pedagogy were represented in the e-learning software for evaluation purposes. This was undertaken in a similar way to Phase 1, through storyboard creation followed by development updates to the e-learning prototype (discussed previously in section 3.2.6). The student evaluations of the e-learning software were collected via a combination of direct observation of software usage, online survey instrument, and associated focus groups.

3.5.3 Phase 2 Participants

3.5.3.1 Teachers and Educational Experts – Cycle 1

In Phase 2-Cycle 1, the education expert in the field of curriculum, pedagogy and assessment withdrew from the study. Additionally, the teacher from Phase 1 withdrew due to maternity leave; she was then replaced by a novice teacher from a new school. At the time of the study, the teacher had less than one year of experience in teaching GCSE Computer Science.

In summary, the four remaining education experts and one teacher evaluated the Phase2-Cycle1 pedagogical heuristics.

3.5.3.2 Students – Cycle 1

The Phase 1 recruitment was supplemented with a Phase 2 recruitment[20], in which a further eight students were recruited from year-4 (1st year of ICT GCSE); however, thereafter attendance was voluntary and based on student availability: all students participated in the observation study, four of those students responded to the survey, and three of those students attended the focus group.

Previous student participants from Phase 1 now moved to year-5 (2nd year of the ICT GCSE): six students participated in the observation study, the same six students responded to the survey, and four of those students attended the focus group. It should be noted that the year-5 students had worked with the previous version of the e-learning software.

3.5.3.3 Teachers and Educational Experts – Cycle 2

In Phase2-Cycle2, the teacher from Phase2-Cycle1 withdrew from the study, but was replaced by a teacher with over ten years of experience in Key Stages 3, 4, and 5 computer science, and with additional experience as a moderator for OCR GCSE Computing.

One of the education experts was unable to give feedback within the requisite timeline; therefore, three education experts in the fields of computer science, education, and educational media provided their feedback in Phase2-Cycle2.

3.5.3.4 Students – Cycle 2

In cycle 2, all student participants from cycle 1 were given the opportunity to attend the study; however, considering the voluntary basis and student availability, Phase2-Cycle2 research results are based on four students from year-5 (2nd year of the ICT GCSE) and three students from year-4 (1st year of ICT GCSE). Both the year-5 and year-4 students had worked with the previous version of the e-learning software. From year-5, four students attended the observation study, three of those students responded to the survey, and the same three students attended the focus group. From year-4, three students attended the observation study, two of those students responded to the survey, and the same two students attended the focus group.

3.5.4 Phase 2 Action Research Activities

Each Phase 2 research cycle was broken down into the following activities. Many of the activities and instruments in Phase 2 are similar to those in Phase 1; hence, where appropriate, previous sections are referenced.

Specify Learning (Update Pedagogy)

1. Literature review of learning theories.

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[20] As discussed in section 3.4.2.1; participant recruitment was undertaken via a presentation to both the students and their guardians accompanied by information letters and consent forms.

2. Research on GCSE Computer Science curriculum – focus on algorithms and computational thinking.
3. Refine the pedagogical heuristics (refer to section 3.5.4.1).
4. Evaluation of pedagogical heuristics from teacher and education experts (refer to section 3.5.4.2).

Diagnosing

5. Specify what aspects of the pedagogical heuristics are to be evaluated in this cycle.

Planning Action

6. Secure ethics approval for Phase 2 research in schools.
7. Secure informed consent from headteacher, teachers, students and parents.
8. Plan and schedule the activities of the observation study with schools.

Taking Action

9. Update the instructional design of the e-learning Software – Storyboards (refer to section 3.2.6)
10. Update and test the e-learning software prototype (refer to section 3.2.6).

Evaluating Action

11. Distribute the VARK learning styles questionnaire. This is the same as Phase 1 (refer to section 3.4.4.3).
12. School-based observation of the usage of e-learning software (refer to section 3.5.4.3).
13. Distribute survey instrument. This is the same as Phase 1 (refer to section 3.4.4.5).
14. Undertake focus group (refer to section 3.5.4.4).
15. Merge and interpret results from different research strands.
16. Provide feedback back to participants (member checking) to verify that researcher interpretation is correct.

A mixed methods procedural diagram is shown in Figure 12, which gives a visual representation of points 4 and 11 to 15.

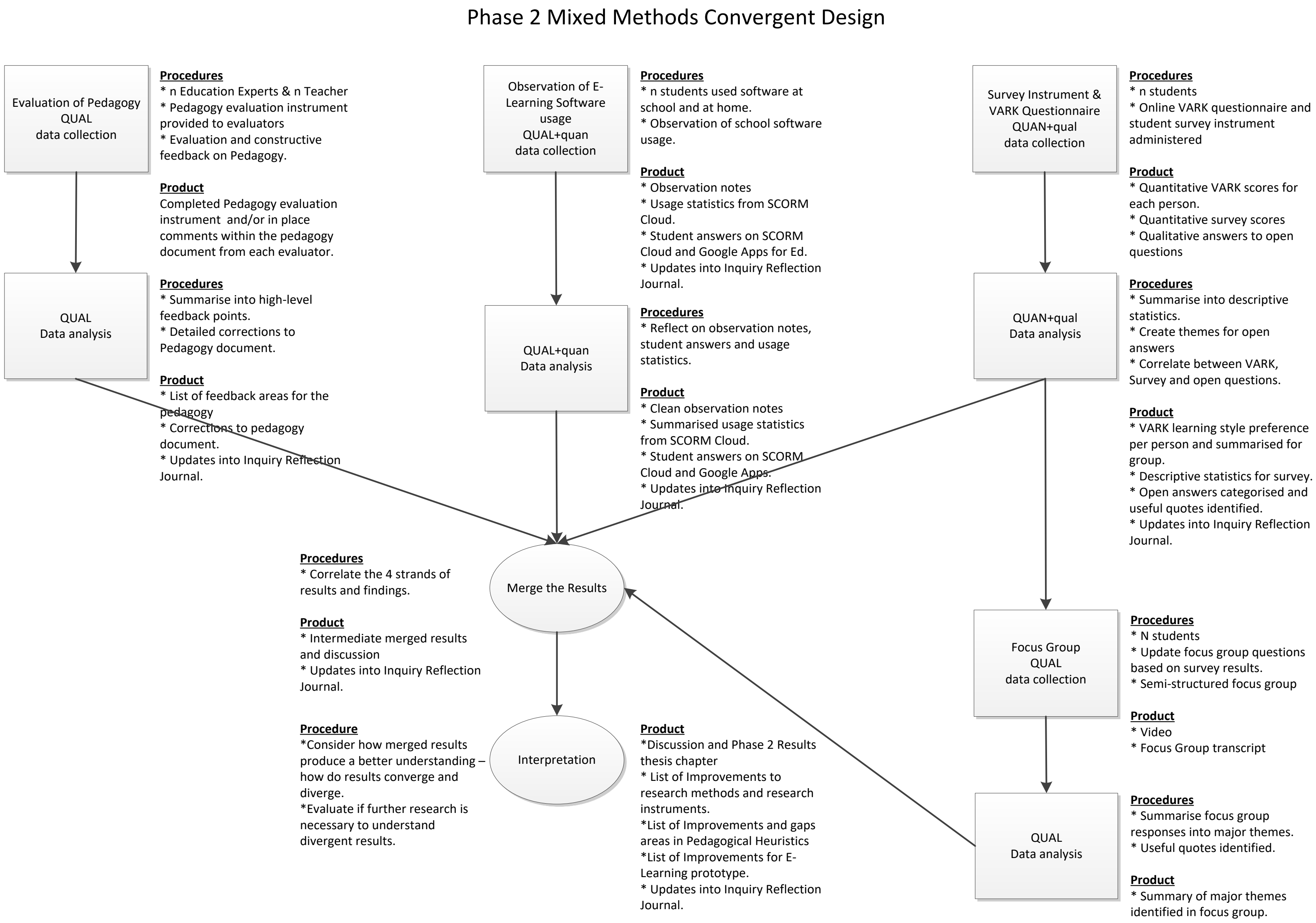


Figure 12: Phase 2 - mixed methods convergent design

3.5.4.1 Phase 2 Synthesis of Pedagogical Heuristics

Based on the findings of Phase 1, a focused literature review was undertaken resulting in the refinement of existing heuristics and the addition of new e-learning pedagogical heuristics for GCSE Computing. This formed the basis of the Phase2-Cycle1 e-learning pedagogy.

Based on the findings of Phase2-Cycle1, a focused literature review was undertaken resulting in the refinement of existing e-learning pedagogical heuristics for GCSE Computing. This formed the basis of the Phase2-Cycle2 e-learning pedagogy.

As previously outlined, the pedagogy literature review is outlined in section 2.4 and the e-learning pedagogical heuristics are discussed in Chapter Four.

3.5.4.2 Evaluation of Pedagogical Heuristics from Teacher and Education Experts

The composition of the pedagogy evaluation group in Phase2-Cycle1 is outlined in section 3.5.3.1. Evaluators were given up to two months to review the e-learning pedagogy document and feedback was provided in the Pedagogy Evaluation Feedback document (refer to section 6.2.1) and/or inline comments and corrections within the pedagogy document. Where the feedback was unclear to the researcher, then one-to-one interviews were used to clarify.

The evaluation feedback was analysed and incorporated into the research at the start of Phase2-Cycle2. This pedagogical feedback is summarised in sections 6.4.2, and reported in full detail in Vol 2 Appendix A.

For Phase2-Cycle2, a similar approach was undertaken, which informed Phase 3. The composition of the pedagogy evaluation group in Phase2-Cycle2 is outlined in section 3.5.3.3. This pedagogical feedback is summarised in section 6.4.3 and reported in full detail in Vol 2 Appendix A.

3.5.4.3 Observation Study

For each Phase 2 cycle, after the e-learning software prototype was updated, an observation study was organised by the researcher to observe student usage of the e-learning software. The e-learning software test tool is discussed in section 6.2.2, and the specific versions used in cycle 1 and cycle 2 are discussed in sections 6.2.2.2 and 6.2.2.3, respectively.

Based on lessons learnt from Phase 1, a more detailed technical environment specification (refer to section 6.2.5) was distributed to the schools and the participants prior to the observations. This was to ensure participants used the e-learning software in an appropriate environment setup. Likewise, a more rigorous set of technical checks were undertaken in each school's ICT lab to ensure their adherence to the technical environment specification.

Due to a school scheduling conflict, the two student groups participating in Phase 2 could not be scheduled for a single observation study, thus two observation studies took place. However, both observations were organised on school premises in the same ICT lab; the observations started at 13:30, after the students had completed their school day and had time for a short break. Fifteen minutes was allocated to an introduction and organising the participants; then the student participants used the e-learning software prototype for a period of 1 hour and 10 minutes, allowing the research investigator to observe the direct usage of the software.

At the end of the observations, the students were asked to progress and complete the remaining sections of the e-learning software asynchronously from home.

To minimise any potential bias and differences between the groups, instructions and basic training was provided to each group of participants via a standard template; thereafter, the researcher provided minimal guidance and support.

Notes from each observation study were documented informally in handwritten notes, and transcribed later after each observation.

The student answers posted onto the SCORMCloud platform and the Google Apps for Education collaborative learning environment were reviewed for: correctness, whether they were attempted, number of attempts and, where available, the duration taken to answer.

High-level usage patterns were also collected from the SCORMCloud platform showing the number of accesses and the duration of each access to the learning material.

This information was then correlated and reflected upon to identify any major themes that required further investigation in the focus group.

3.5.4.4 Focus Group

The Phase 2 focus groups followed a similar approach to that detailed in Phase 1; refer to section 3.4.4.6. Specific details of the Phase 2 focus groups are as follows:

1. **Phase2-Cycle1:** This cycle was broken into two focus groups since the year-5 group had previous experience of the e-learning software.
    a. **Year-5 Group:** The focus group duration was 88 minutes and was facilitated by the researcher in the School's ICT Lab. The projector was available to show the screens of the e-learning software.
    b. **Year-4 Group:** The focus group duration was 70 minutes, was facilitated by the researcher in the School's ICT Lab. The projector was available to show the screens of the e-learning software.
2. **Phase2-Cycle2:** The focus group duration was 75 minutes and was facilitated by the researcher in the school's ICT Lab. Year-4 and year-5 students were merged into a single focus group. The projector was not available to show the screens of the e-learning software, but paper-based screen prints were used instead.

The focus group transcripts were analysed thematically to identify any key themes raised in the discussion, and evaluated in terms of the value of student responses as quotable comments.

3.5.5 Interpretation

As with Phase 1, the findings from the e-learning pedagogy review, observation study, VARK questionnaire, student survey and focus group were examined holistically to understand whether the different research strands converge or diverge, to identify areas requiring further investigation and areas that give direction to the remainder of the study.

The teacher / expert feedback on the e-learning pedagogy are reported in summary form in 6.4.2 and 6.4.3, and elaborated thematically in full form in Vol 2 Appendix A.

As discussed in section 3.4.5, the Phase 1 and 2 findings from student usage of the e-learning software prototype are merged and reported together. The findings are reported in summarised form in section 6.5, and in full form in Vol 2 Appendix B.

3.5.6 Phase 2 – Ensuring Validity and Trustworthiness

The approaches to trustworthiness utilised in Phase 1 were also used in Phase 2, for a discussion of these approaches please refer to section 3.4.6. However, in Phase 2 some additional factors and activities further strengthen the credibility, dependability and confirmability of the study.

Considering the researcher's involvement with some participants from Phase 1 onwards and the remaining participants in two cycles of action research, the strengthening of Credibility is achieved via prolonged engagement and persistent observation (Creswell 2007; Guba & Lincoln 1989; Lincoln & Guba 1985). Prolonged engagement builds trust with participants, which in turn helps in identifying and considering distortions and misinformation that might creep into the study. Additionally, the persistent observation of participants helps to identify characteristics of the situation most pertinent to the area of study, and to allow a follow up on those areas in more detail.

In Phase 2, an additional activity to maintain a reflective journal was undertaken; this is an approach used often in action research (O'Brien 2001; Taylor 2006) and supports all aspects of trustworthiness, but specifically is a major technique in supporting confirmability (Lincoln & Guba 1985).

The reflective journal is a kind of diary of the research progress and includes a variety of information about the researcher and the thinking that underpins the direction of the research and any methodological decisions. This information can then potentially be used by an inquiry auditor to get a better understanding of the rationale used in the research and, in particular, whether the researcher's biases have influenced the research findings.

There is no widely accepted format or structure for a reflective journal; however, based on suggestions from Taylor (2006) and Lincoln and Guba (1985), the researcher included a subset of the following information:

1. Date,
2. Daily schedule and logistics of the study,
3. Personal Diary providing an opportunity for catharsis and reflection, and

4. Methodologic log in which methodological decisions and accompanying rational are recorded (refer to section 3.4.6.3).

3.6 Phase 3: Final Experiment

3.6.1 Objectives

Whereas the previous mixed methods phases had a qualitative priority, Phase 3 used a convergent parallel mixed methods design with a quantitative priority. As previously outlined, the purpose of this phase was to further validate the findings of the first two phases by confirming them using quantitative methods, and attempting to generalise them to a wider population. Specifically, this phase measured whether adherence to the e-learning pedagogy in the design of e-learning software influenced student learning and/or motivation.

3.6.2 Phase 3 Participants

3.6.2.1 Teachers and Educational Experts

In Phase 3, the teacher from Phase2-Cycle2 withdrew from the study, but was replaced in the e-learning pedagogy review by another experienced computer science teacher.

Two education experts in the fields of computer science, and education and educational media provided their feedback on the Phase 3 pedagogical heuristics.

3.6.2.2 Students

The Phase 3 study comprised two UK comprehensive schools offering the Computer Science GCSE (2016 Specification). At the time of the study (January 2017), student participants were starting the 1st year of the GCSE. Table 7 summarises the Phase 3 student participants.

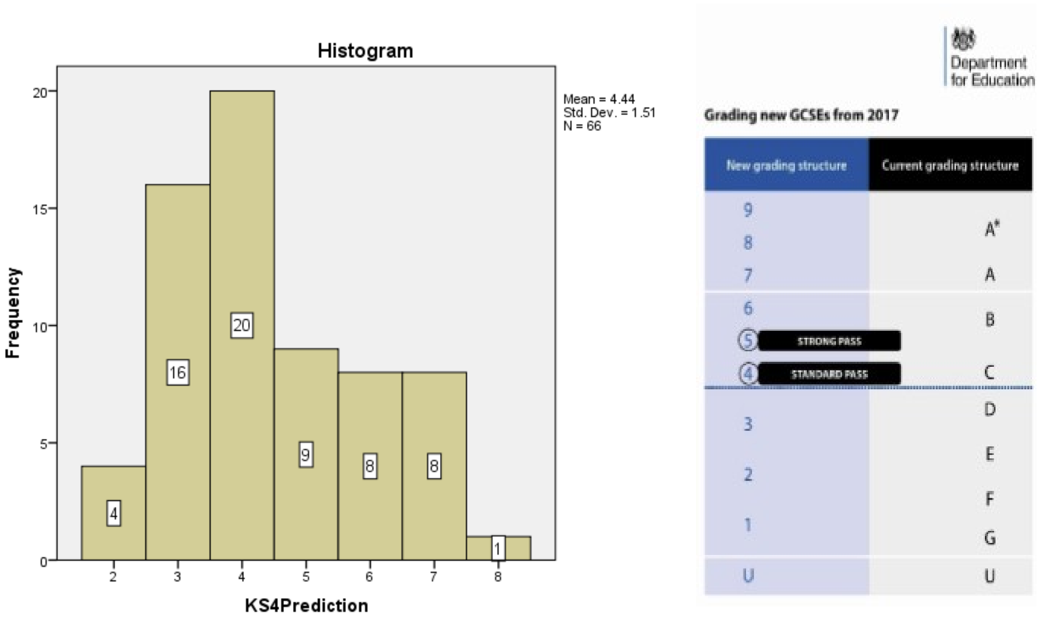
School	Participants	Male Participants	Female Participant
School 1	34	34	0
School 2	32	21	11
Total	66	55	11

Table 7: Phase 3 - student participants

Student participants are evenly split between the schools and the overall number of female participants (17%) is broadly aligned with national statistics published by the Department for Education (DfE) (2017), reflecting 20% of students entered in the 2015/2016 Computer Science GCSE were female.

The participating schools were self-selecting, based on the teachers' interest in participating in the research. However, the self-selection process did not extend to the student participants; after providing informed consent, all students undertaking the 1st year of the Computer Science GCSE participated in the study. Therefore, there is a random cross-section of student ability as represented by the teachers' Key

Stage 4 (KS4) predictions shown in Figure 13. KS4 predictions range from 1 (A*), 8 (A) to 4 (E-F) with a mean between a Standard and Strong Pass (M=4.29 SD=1.50) and median of Standard Pass (Mdn=4).



(DFE 2017)

Figure 13: Phase 3 - frequency distribution of Key Stage 4 predictions.

Considering these sample characteristics, the Phase 3 student participants are deemed representative of the wider GCSE Computer Science population.

3.6.3 Phase 3 Experiment Design

In Phase 3, quantitative and qualitative methods were used to collect and analyse data, and the results were integrated into a single view; as such, the final experiment is classified as a mixed methods triangulation approach (Borrego et al. 2009).

The quantitative experiment measured whether there were improved student assessment results from e-learning software that is designed in adherence with the pedagogical heuristics synthesised in this research. This leads to the following experiment hypothesis:

- H_0: The use of e-learning software designed in adherence to the pedagogical heuristics presents no difference in student learning performance.
- H_1: The use of e-learning software designed in adherence to the pedagogical heuristics presents improved student learning performance.

The e-learning software prototype developed in this research study was critically evaluated against the heuristics to identify its pedagogical value. This evaluation provides a quantifiable measure of the e-learning Software's adherence to the pedagogical heuristics (refer to section 6.2.2.4).

Before the experiment execution period began, the participating high-school teachers administered to their students a standardised pre-test to act as a baseline for learning. Directly after the experiment, the same test was administered as a post-test. Statistical analysis of pre- and post-test results was undertaken to identify whether learning occurred, and if it was statistically significant. Furthermore, parametric statistical analysis was used to theorise the potential learning performance possible within the Computer Science GCSE from use of the software prototype.

The quantitative analysis aimed to give statistically significant evidence that the use of e-learning software with increased adherence to the pedagogical heuristics presents an improved student learning performance. However, this does not give clear insight into the underlying reasons for the results; this insight is given by the online distribution of the student survey instrument. This survey instrument collected both quantitative and qualitative data. This was further supplemented by the online distribution of the VARK questionnaire, previously used in Phases 1 and 2. The mixture of quantitative and qualitative data sources enabled the triangulation of student feedback with assessment performance, thereby putting the quantitative performance results in context.

3.6.4 Phase 3 Research Activities

1. Literature review of learning theories.
2. Research on GCSE Computer Science curriculum – focus on algorithms and computational thinking.
3. Refine the pedagogical heuristics.
4. Evaluation of pedagogical heuristics from teacher and education experts (refer to section 3.6.4.2).
5. Update the instructional design of e-learning software – Storyboards (refer to section 3.2.6).
6. Update and test e-learning software prototype (refer to section 3.2.6).
7. Secure ethics approval for research in schools.
8. Secure informed consent from headteacher, teachers, students and parents.
9. Distribute VARK learning styles instrument (refer to section 6.2.3).
10. Administer student pre-test (refer to section 6.2.6 and 3.6.4.4).
11. School-based usage of e-learning software (refer to section 3.6.4.3).
12. Administer student post-test (refer to section 6.2.6 and 3.6.4.4).
13. Distribute the survey instrument. This is the same as Phase 1 (refer to section 3.4.4.5).
14. Merge and interpret results from different research strands.

A mixed methods procedural diagram is shown in Figure 14, which gives a visual representation of points 4 and 9 to 14.

Phase 3 Mixed Methods Convergent Design

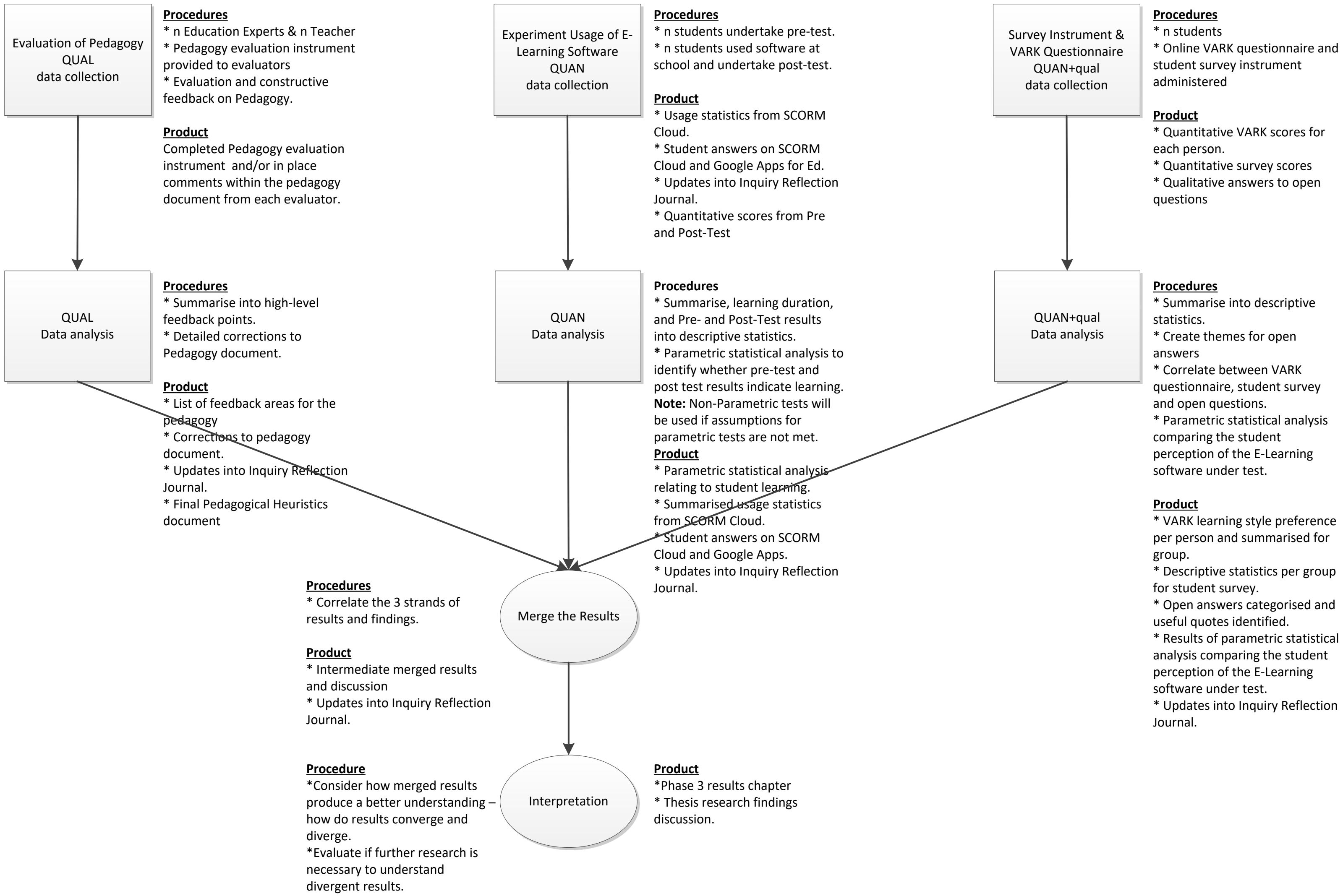


Figure 14: Phase 3 mixed methods convergent design

3.6.4.1 Phase 3 Synthesis of Pedagogical Heuristics

Based on the findings of Phase2-Cycle2, a focused literature review was undertaken resulting in the refinement of existing e-learning pedagogical heuristics for GCSE Computing. This formed the basis of the Phase3 e-learning pedagogy.

As previously outlined, the pedagogy literature review is outlined in section 2.4, and the e-learning pedagogical heuristics are discussed in Chapter Four.

3.6.4.2 Evaluation of Pedagogical Heuristics from Teacher and Education Experts

The composition of the pedagogy evaluation group in Phase3 is outlined in section 3.6.2.1. The evaluation of the pedagogical heuristics followed the same procedures (refer to section 3.5.4.2) and instrument (refer to section 6.2.1) as used in Phase2-Cycle2.

Based on the pedagogy's mature state, the feedback was minimal, but was incorporated into the final version of the e-learning pedagogy document. This pedagogical feedback is summarised in section 6.4.4, and the final e-learning pedagogy document is in Vol 2 Appendix D.

3.6.4.3 School-based Use of E-learning Software

A key component of the Phase 3 research was the e-learning software usage experiment. After the four levels of the Phase 3 e-learning software prototype were developed (refer to sections 6.2.2 and 6.2.2.4), they were provided to two UK comprehensive schools to be incorporated into their teaching of the GCSE Computer Science topics of algorithms and computational thinking.

The experiment was organised on school premises in each school's ICT lab; however, to ensure uniformity across experiment sites a detailed technical environment specification was distributed to the schools and used to check and confirm environment conformance (refer to section 6.2.5).

The experiment was facilitated by the teachers associated with each school; however, to minimise any potential bias and differences between the groups, the same instructions and training was provided to the teachers. Additionally, a Phase 3 Research Protocol Confirmation document was distributed to the teachers ahead of the study; this documented the steps and activities to be followed during the study (refer to section 6.2.7). The teachers were requested to provide minimal additional guidance to students, and to not provide additional learning material or teaching.

In keeping with heuristic 19: Optimise essential processing by segmenting learning material and providing pre-training, to ensure the students were able to effectively use the software, a quick tips sheet was provided which outlined e-learning software functionality. This was further supplemented by tutorial videos in the e-learning software.

This experiment was **not** treated as an observation study; hence, there are no experiment research notes. The student answers posted onto the SCORMCloud platform and Google Apps for Education were reviewed for: whether they were attempted, number of attempts and, where available, the duration taken to answer.

High-level usage patterns were also collected from the SCORMCloud platform showing the number of accesses and the duration of each access to the learning material.

The e-learning software contained approximately five hours of learning material; both schools completed the teaching engagement in two weeks of in-class and homework sessions. School1 used four in-class sessions and School2 used five in-class sessions; an analysis of student learning time is presented in section 6.6.7.2. The teachers returned the Research Protocol Confirmation document to confirm the research procedures were followed, and notified that the experiment and test results were not impacted by any exceptional circumstance. Finally, at the end of the session, the students undertook the post-test.

3.6.4.4 Pre- and Post-Test

As outlined previously, before the experiment execution period began, the participating high-school teachers administered to their students, under exam conditions, a pre-test. Exam conditions are defined by the following test controls:

- 35 minutes are allocated to answer all questions.
- The examination environment is quiet, comfortable, and without any notable distractions.
- Students are seated equidistantly spaced to avoid copying.
- Teacher acts as invigilator to avoid students using unfair means (copying, etc.).
- Student Instructions are:
    - Use black ink or ballpoint pen. Use pencil only for drawing.
    - Answer all questions.
    - You must answer the questions in the spaces provided.
    - If you make a mistake, cross through the incorrect answer.
    - Do all rough work in this book. Cross through any work that you do not want to be marked.
    - You are free to answer questions that require a coded solution in whatever format you prefer as long as your meaning is clear and unambiguous.
    - You must not use a calculator.

This pre-test provided a baseline for learning performance. Directly after the experiment period, the same test was administered under the same exam conditions as a post-test. This ensured that the pre- and post-test results are directly comparable. The test instrument is discussed in detail in section 6.2.6.

As discussed in 6.2.6.1, to reduce the possibility of the participants remembering the test between pre- and post-tests, there was a minimum 2-week delay between the pre- and post-tests. However, to reduce the potential for unintended learning, the time between pre-test, experiment, and post-test was kept minimal (less than three weeks). Finally, before the post-test, students communicated whether they had accessed other learning material on the subject matter, thereby explicitly counteracting the issue of unintended learning.

3.6.5 Data Collection, Analysis and Reporting

In Phase 3 there was an increased focus on quantitative results and statistical analysis. As standard practice in quantitative analysis, a codebook was created to keep a meticulous log of any pre-treatment, variable coding, decisions, and statistical tests taken in Phase 3 (Pallant 2001; Litwin 1995). For reference, this codebook is included in Vol 3 Appendix M.

This section provides a high-level discussion of some of the keys decisions and approaches taken in the Phase 3 statistical analysis. Also, during Phase 3, certain decisions were taken during the statistical analysis that may at a first view seem to be non-standard. This section also discusses the theoretical foundation for those decisions.

3.6.5.1 Parametric vs Non-Parametric Tests

Statistical procedures are broadly split into two groups: parametric and non-parametric tests. Parametric tests require ratio or interval data and have a number of assumptions that should be met, in particular relating to the distribution of the data. Non-parametric tests are applicable to all four measurement scales, are less restrictive in their assumptions, and are distribution free (MacKenzie 2013; Field 2013; Pallant 2001). The consensus is that by virtue of their superior power[21], as long as their assumptions are reasonably met, parametric tests should be preferred. However, there is academic debate on what to do when the assumptions for parametric tests are not met; MacKenzie (2013) offers three options:

1. Proceed with parametric tests.
2. Correct the violation by cleaning or transforming the data, and then proceed with parametric tests.
3. Proceed with non-parametric tests.

Some researchers argue that parametric tests are reasonably robust to assumption violations (Box 1953; Norman 2010), and this can offset the reduction in power from using non-parametric tests. Field (2013) offers a balanced discussion on data transformation and cleaning, in that it can be a valuable tool in certain scenarios, but can also add an additional layer of complexity which, if ill-considered, can negatively impact the statistical model being used. Also, in the worst case, data transformation and cleaning could be viewed as a convenient tool to manipulate the data to fit the research objective. The third option, MacKenzie (2013) argues, is incorrectly becoming a de-facto standard: to jump straight to non-parametric tests. He offers a convincing review of HCI research in which researchers have moved straight to non-parametric tests even on interval and ratio data, without considering the impact on reduced statistical power. Citing

[21] Power meaning a greater ability to draw the right statistical conclusions i.e. rejecting the null hypothesis where appropriate, or not if there is insufficient basis to do so.

two examples (Perugini et al. 2007; Munteanu et al. 2006), MacKenzie (2013) discusses the praiseworthy approach, to consider both parametric and non-parametric analysis and adjust accordingly if there is any disparity.

Field (2013) also offers another partial solution, which is underpinned by the prevalent usage of statistical software and computational power: the Bootstrap procedure. The Bootstrap option overcomes issues of non-normal sample data; it estimates the sampling distribution by treating the sample data as a population. Field (2013, p.199) succinctly discusses the approach: "*The sample data are treated as a population from which smaller samples (called bootstrap samples) are taken (putting each score back before a new one is drawn from the sample). The parameter of interest (e.g., the mean) is calculated in each bootstrap sample*." This process can be repeated (i.e. 1000 times) to build an accurate confidence interval for the parameter under analysis.

Building on MacKenzie (2013) and Field (2013) this research will often report results from parametric and non-parametric tests, and make extensive use of the bootstrap option. In summary, the following strategy was adopted when research data did not fully meet the assumptions for parametric tests:

1. Parametric tests were preferred for ratio and interval variables,
2. Where assumptions were not met for parametric tests; typically, due to a non-normal distribution, then:
    a. The bootstrap option was employed, and
    b. Appropriate non-parametric tests were employed in parallel to confirm the parametric and bootstrap tests.

3.6.5.2 Correlation analysis

Within Phase 3, there was extensive use of correlation analysis to identify relationships between experiment variables. The Pearson product-moment correlation coefficient (parametric) and the Spearman rank correlation coefficient (non-parametric) are two widely used tests for the correlation between two variables. There is some debate on the comparative power of each of the tests (de Winter et al. 2016), and various guidelines on which test is best suited in a given scenario (Pallant 2001; Field 2013; de Winter et al. 2016; Fowler 1987). However, the consensus is that Pearson's *r* can be impacted by a non-normal distribution (how big an impact is in debate) and is strongly impacted by outliers (Pallant 2001; Field 2013; de Winter et al. 2016). Whilst Spearman's Rho is distribution-free, has minimal impact from outliers, but can be strongly affected by small sample sizes (Pallant 2001; Field 2013). Pallant (2001, p.133) warns that "*in small samples n=30, you may have moderate correlations that do not reach statistical significance at the traditional p< .05*."

To compensate for this, Pallant (2001) recommends that you still need to report the statistical significance, but the focus should be more on the strength of the relationship. Field (2013) offers similar guidance, and goes further in recommending a focus on the Bootstrap Confidence Interval (2013).

In summary, the correlation analysis in Phase 3 was undertaken using Spearman's Rho, including outliers. The correlation coefficient used to measure the size of the effect was evaluated in terms of Cohen's (Cohen 1988; Pallant 2001; Field 2013) small, medium and large effect, where:

- Small r=.10 to.29
- Medium r = .30 to .49
- Large r = .50 to 1.0

Significance is reported, but is not used as cut-off; instead, emphasis is placed on the strength of the effect and the bootstrap confidence interval. Correlation results are reported in two tiers that reflect the strength of the result:

1. **Tier 1**: A correlation effect of ±.1 or more, and p < .05
2. **Tier 2**: A correlation effect of ±.1 or more, and the Bootstrap Confidence Interval (CI) does not cross over the 0 threshold (i.e. CI is between -.09 and 1 or .09 and -1)

3.6.5.3 Treatment of Outliers

For the purposes of this study, outliers are defined as scores that are 1.5 x Interquartile Range. They were identified by a combination of histograms and boxplots. As a general approach, outliers were first verified as not being transposition errors. Additionally, they were investigated against other variables to try to identify an explanation of the result. Examples of variables that were investigated against outliers include:

1. Duration of engagement with the e-learning software,
2. Pre-Test / Post-Test results,
3. Open question responses,
4. Experience with e-learning software and their use of the internet, and
5. Key Stage 4 predictions.

According to Cousineay & Chartier (2011), there is academic discussion and various recommendations on how to deal with outliers, but there is no universally accepted approach. Although outliers can have a potentially significant impact on parametric tests (Field 2013), the removal of unexplained outliers can cause an underestimate of the true variability of the data, and can negatively affect representativeness (de Winter et al. 2016; Pallant 2001). Furthermore, alternate, approaches to transform outlier data can also have an unintended impact on the statistical analysis (Cousineay & Chartier 2011).

In summary, this research primarily reports descriptive statistics including outliers, but also reports, as a reference, descriptive statistics without outliers. This approach indicates the potential impact of the outlier(s) and gives input on whether subsequent statistical tests should be carried out, with or without outliers.

3.6.5.4 Descriptive Statistics

The direction set in the previous sections means that often parametric and non-parametric tests are run in parallel. As such, descriptive statistics will typically cover both mean and median, and their associated measure of spread. Meaning descriptive statistics will take the form of summary tables and histogram diagrams that focus on mean, median, interquartile range, upper and lower limits, standard error, and standard deviation.

In addition, skewness and kurtosis will be reported, as well as results from the Kolmogorov-Smirnov test; this will give clarity on the distribution of the data, and feed into decisions on which statistical test takes priority and are reported.

3.6.5.5 Pre-Test Post-Test Analysis

The pre-, post-test statistical analysis focuses primarily on the following variables: Key Stage 4 Indicator, Level-1 Duration, Level-2 Duration, Level-3 Duration, Level-4 Duration, Level-3 and -4 Combined Duration, All Levels Combined Duration, %Pre-Test, %Post-Test, and %Change.

Duration variables were exported from SCORMCloud or summed, based on the exported values. Key Stage 4 Indicators were provided directly by the teachers. %Pre-Test and %Post-Test are the percentage values of the agreed moderated marks for each of the students, and %Change is the difference between %Post-Test and %Pre-Test.

Prior to any statistical analysis, the following data cleaning steps were carried out on pre-, post-test data:

1. Removal from pre-test / post-test of all students who did not get a result for both tests. This step ensures two controlled test results are recorded that can be used to measure learning performance.
2. Removal from pre-test / post-test of all students who answered yes in the survey instrument to using other learning materials. This step ensures that the post-test measures learning derived from e-learning software and CLE activities, and avoids the potential for bias brought about by unintended additional learning.
3. Removal of all students from pre-test / post-test who spent zero time on both Level-3 and Level-4. The material tested in the pre-, post-test is directly related to Level-3 and Level-4; the inclusion of students who had spent zero time on these levels would include an unintentional bias to the learning performance results.

The pre-, post-test variables were first summarised by descriptive statistics. Where the assumptions for parametric testing were met, then a Paired Sample T-Test was carried out between %Post-Test and %Pre-Test.

Where the assumptions for parametric testing were **not** met, then the same Paired Sample T-Test was carried out with Bootstrapping, and a Wilcoxon Signed-Ranks Test was carried out to verify.

One-Sample T-Tests were carried out on %Pre-Test and %Post-Test to map each of them towards the grade boundaries for the Computer Science GCSE (2016 Specification).

Statistical inference is reported to a 95% confidence interval in order to be able to generalise towards the wider GCSE Computer Science population.

3.6.5.6 Survey Instrument Analysis

As in previous phases, the data from the student survey instrument was collated automatically via the online survey tool, and exported in comma-separated value (CSV) format. This was then imported into a spreadsheet program for data preparation and finally transposed to a statistical package for further analysis.

The survey instrument responses were reported as descriptive statistics. Since the instrument focuses primarily on the students' perception of the e-learning prototype, there was no expectation to generalise to the wider GCSE population, and no expectation of a normal distribution. However, several variables from the survey instrument, including the IMMS responses, were used in correlation analysis against %Pre-Test, %Post-Test and %Change variables.

The responses to open questions were thematically grouped and evaluated in terms of their value as quotable comments.

As discussed in section 6.2.4.1, analysis was performed to verify alternate-form and internal consistency reliability in the Phase 3 survey instrument.

3.6.5.7 Instructional Materials Motivation Survey (IMMS) Analysis

As standard practice, the IMMS instrument was reported on the motivational sub-categories and not the 36 individual questions (J. M. Keller 1987b; Keller 2006; Cook et al. 2009). Motivation sub-categories of attention, relevance, confidence and satisfaction were:

1. reported as descriptive statistics,
2. assessed on whether the inter-group results had a statistically significant difference, and
3. assessed for internal reliability using Cronbach's alpha.

3.6.5.8 VARK Learning Styles Analysis

In Phase 3, the approach used for data collection and the preliminary analysis of VARK learning styles responses remains the same as is described in 3.4.4.3. However, in addition, the responses were imported to a statistical analysis package to assess whether the inter-group results for the modal sub-categories have a statistically significant difference.

3.6.6 Interpretation

As with the previous phases, in Phase 3, the two data sets were collected and analysed separately and independently from each other using typical quantitative and qualitative procedures. After the data had been analysed, the results were merged and interpreted to identify to what extent, and in what ways, the two sets of results converged, diverged or related to each other. In Phase 3, the interpretation was based primarily on quantitative results, and qualitative data was used to give an underlying explanation of these results.

After the Phase 3 results were analysed (refer to section 6.6), there followed a final interpretation and discussion of how the findings of Phase 1 and Phase 2 converged or diverged from the results of Phase 3, and what had been learnt from the combination of results from all three phases (refer to Chapter Seven).

3.6.7 Phase 3 – Ensuring Validity and Trustworthiness

Since Phase 3 had a quantitative priority, the validation strategies used for the aforementioned experiment are associated with Internal Validity, External Validity (Generalisability), Reliability and Objectivity.

To ensure that the above measures of validity were achieved, several controls were implemented to try to rule out alternative explanations of the experiment results, ensure the experiment was objective, can be repeated and can be generalised to the wider population in question.

1. Research instruments and procedures were documented and available for review, audit and reuse in a repeat of the experiment. Reliability and validity of research instruments is discussed in sections 6.2.3.1, 6.2.4.1, and 6.2.6.1.
2. As part of the development of the research instruments and procedures, they were reviewed by other experienced researchers and vetted as part of the ethics approval process, thereby ensuring there is no inherent bias.
3. Experiment procedures were standardised by the use of standard experiment instructions and training. Additionally, the research procedures were confirmed by teachers in the Research Protocol Confirmation document.
4. The experiment environment was generalisable to the student's typical learning environment since it is their School's ICT lab.
5. The ICT labs were confirmed quiet, comfortable, clean and tidy and without any notable distractions.
6. A feedback process was instigated in case any distracting event occurs during experiment execution.
7. The learning measurement instrument (pre- and post-test) was accurate and targeted at the right level since it was based on examination material from the relevant examination boards.
8. Learning was measured accurately by using the same test for the pre-test and for the post-test, but allowing a minimum of two weeks between to give students time to forget the test. It should be noted that the test was problem-based, therefore difficult to memorise, the students were not given the correct answers and were not informed they would take the same test as a post-test.
9. To reduce the potential for unintended learning the time between pre-test, experiment and post-test was kept minimal (no more than 3 weeks).
10. Before the post-test, students communicated whether they had accessed other learning material on the subject matter.

11. The student sample was selected from GCSE Computer Science students and was representative of the target population (refer to section 3.6.2.2).
12. The use of a non-trivial sample (n = 66) helps to improve confidence that the experiment is generalisable to the overall population.

3.7 Research Methods for the Development of the E-learning Evaluation Protocol

At the outset of this research, the development of an e-learning evaluation protocol was not envisaged as a research objective. However, the Phase 1 Pilot identified a clear need for such an instrument for use in both formative and summative assessment. It was at this point that the development of an e-learning evaluation protocol became a secondary research objective.

The development of the e-learning evaluation protocol was loosely synchronised with the qualitative research methods and timelines used to develop the e-learning pedagogy; they intersected in Phase 1, Phase2-Cycle2 and Phase 3. This intersection was due to:

1. The evaluation protocol being based on the pedagogical heuristics; hence, it was updated in parallel to their evolution.
2. Furthermore, the e-learning software prototype was used as a test tool for the piloting and usage of the evaluation protocol.

3.7.1 Phase 1 Procedures: Identifying the Need for an E-learning Evaluation Protocol

During the Phase 1 e-learning design activity (storyboard creation), it became apparent that even with the best of intentions, it is not realistic to create e-learning software that gives a consistent and comprehensive coverage of all the heuristics. This raised the view that each e-learning software design / development would have a specific pedagogical coverage that would need to be assessed in some way.

In response to this need, an initial Phase 1 e-learning evaluation rubric was hastily constructed, and was used by the researcher to assess the Phase 1 e-learning prototype (Algorithms V04a). The rubric and the evaluation results are outlined in section 6.7.1.

The rubric was constructed based on the perceived needs at the time, was not informed by a significant literature review or research, and in retrospect was quite rudimentary in nature. However, as with all good pilots, it served as a strawman to be deconstructed. The Phase 1 evaluation rubric added significant value in identifying shortcomings and highlighting the limited research in this area; the latter point was eventually confirmed in Phase 2.

3.7.2 Phase 2: Piloting the E-learning Evaluation Protocol

3.7.2.1 Objectives

Considering that Phase 1 identified the need for an e-learning evaluation protocol and served as a mock-up to deconstruct, Phase2–Cycle2 focused on the development and pilot of the 1st stable version of the e-learning evaluation protocol.

3.7.2.2 Phase 2 – Cycle 2 Participants

Three education experts were involved in the review of the e-learning evaluation protocol in Phase 2; these were the same experts involved in the review of the e-learning pedagogy. All the experts were senior university academics in the fields of child computing interaction, computer science, and education and educational media.

3.7.2.3 Phase 2 Research Activities

1. A literature review of heuristic evaluation protocols.
2. Develop the e-learning evaluation protocol (refer to section 3.7.2.3.1).
3. Evaluation of the e-learning evaluation protocol by education experts (refer to section 3.7.2.3.2).
4. Pilot the e-learning evaluation protocol using the Phase2–Cycle2 e-learning prototype (refer to section 3.7.2.3.3).
5. Merge and interpret results from different research strands (Points 3 and 4).

3.7.2.3.1 Phase 2 – Cycle 2 - E-learning Evaluation Protocol

The Phase2–Cycle2 e-learning evaluation protocol was developed in response to the high-level findings from Phase 1, a significant literature review on heuristic evaluation protocols, and based on the GCSE Computer Science E-Learning Pedagogy v1.5 document.

The evaluation protocol describes both the evaluation process and acts as the evaluation review template in which evaluators provide their feedback.

3.7.2.3.2 Evaluation of the E-learning Evaluation Protocol by Education Experts

The composition of the evaluation group that evaluated the e-learning evaluation protocol is outlined in section 3.7.2.2. The feedback was provided in writing as inline comments within the document; where necessary, the written comments were followed by one-to-one discussions for further explanation.

The evaluation feedback was analysed and incorporated into the research at the start of Phase 3. The education expert feedback on the e-learning evaluation protocol is summarised in section 6.7.2.1.

3.7.2.3.3 Pilot of the E-learning Evaluation Protocol

The practical usage of the e-learning evaluation protocol was piloted by the researcher by evaluating Level-1 and Level-2 of the prototype software. The primary objective of this pilot was not to secure an accurate evaluation of the software, but to identify the effectiveness of the protocol and instrument, and identify any practical areas of improvement. The pilot feedback was analysed and incorporated into the research at the start of Phase 3. The pilot feedback on the e-learning evaluation protocol is summarised in section 6.7.2.2.

3.7.2.4 Data Collection, Analysis and Reporting

The qualitative findings from the education experts and pilot were analysed thematically and holistically on whether they concurred. These findings were used to inform a focused literature review and the update of the Phase 3 e-learning evaluation protocol.

3.7.3 Phase 3: Usage of the E-learning Evaluation Protocol

A workshop was used as the vehicle for the Phase 3 study on the usage of the e-learning evaluation protocol. This is not a standard approach for an e-learning evaluation activity, although ultimately was effective, with some limitations. The medium of a workshop was chosen to give back to the teaching community, in this manner attracting the greatest number of teachers to participate in the research study. Considering the workshop was scheduled in term-time and would necessitate the teachers' absence from school, it was necessary to keep it to one day. In addition, the need to secure research findings meant that two end-of-day focus group sessions had to be accommodated in an already busy schedule. These focus group sessions are not normally part of the e-learning evaluation protocol. The planned agenda for this workshop is represented in Table 8, which was presented to the participants as part of the workshop introduction.

Activity	Time
Introduction and getting to know each other	09:00 – 09:30
E-Learning Heuristics.	09:30 – 10:45
Morning coffee and snack break.	10:45 – 11:00
E-Learning Heuristics .	11:00 – 12:15
Outline the procedure for the E-Learning Evaluation.	12:15 – 12:30
Lunch	12:30 - 13:00
Evaluate an e-learning software (individually).	13:00 – 14:30
Afternoon coffee and snack break.	14:30 – 14:45
Group debrief meeting on evaluation results.	14:45 – 15:30
Focus group - Your thoughts on the day (input into research).	15:30 – 16:30

Table 8: Evaluation protocol workshop agenda (sourced from workshop introductory presentation)

3.7.3.1 Objectives

The Phase 3 workshop focused on the realistic usage of a mature version of the e-learning evaluation protocol by in-service teachers. The primary objective was to secure teacher feedback on the protocol:

specifically, any areas of improvement and whether it is feasible for use in schools. A secondary objective was to secure indicators of its validity and reliability across groups.

3.7.3.2 Phase 3 Participants

3.7.3.2.1 Phase 3 - Education Experts

Following on from the Phase2-Cycle2 evaluation protocol review, two education experts remained involved in the review of the e-learning evaluation protocol in Phase 3; they were senior university academics in the fields of computer science, and education and educational media.

3.7.3.2.2 Phase 3 - Teachers

The Phase 3 workshop was publicised via a flyer and university communications to private schools and educational institutions in which high-school computing, and specifically the Computer Science GCSE, were part of their curriculum. The schools then volunteered appropriate teachers to attend the workshop; the workshop was attended by thirteen teachers representing a total of five private schools and educational institutions.

Of the thirteen teachers attending the workshop, nine participated in the evaluation of the e-learning software. The evaluation was a full evaluation of both content and pedagogical quality; hence, the nine teachers were selected based on being double experts, with knowledge and expertise in teaching and pedagogy, and additional knowledge and expertise in the domain of computer science.

The nine teachers were split into two groups and remained for the evaluation-debrief meeting and the workshop focus group. Please refer to Table 9 for a summary of these teachers' background, qualification and experience.

Evaluator ID	School	Gender	Evaluation Group	Years Teaching	Qualification	Subject Taught
Evaluator1	School 1	Male	Group 1	9	BSc Computer Science PGCE Secondary ICT	Computer Science
Evaluator3	School 2	Male	Group 1	3	BSc Computer Science MSc Information Systems	ICT / Robotics
Evaluator5	School 2	Male	Group 1	15	PhD Elecrical Engineering	Electrical Engineering Computer Science
Evaluator13	Educational Institution 1	Female	Group 1	6	BSc Computer Science MSc ICT in Education	ICT
Evaluator2	School 2	Female	Group 2	12	BScComputer Science MSc Education, Technology and Society	Computer Science / ICT
Evaluator4	School 2	Female	Group 2	10	BSc Computer Science MA Education with IT	ICT / Computer Science
Evaluator8	School 3	Male	Group 2	13	BSc Computing for Industry ECDL Certified Trainer	ECDL and Programming
Evaluator12	Educational Institution 1	Female	Group 2	5	BSc Computer Science. PhD Candidate Educational Technology	ICT
Evaluator14	School 4	Male	Group 2	13	BSc Computer Engineering	Computer Science

Table 9: Evaluation protocol workshop - participant background, qualifications and experience

3.7.3.3 Phase 3 Research Activities Relating to the Evaluation Protocol

1. A literature review of heuristic evaluation protocols.
2. Refine the e-learning evaluation protocol (refer to section 3.7.3.3.1).
3. Evaluation of the e-learning evaluation protocol by education experts (refer to section 3.7.3.3.2).
4. Workshop
   a. Secure informed consent from teachers to participate in research activities during the workshop.
   b. Train teachers on the pedagogical heuristics (refer to section 3.7.3.3.3).
   c. Outline the procedure for the e-learning evaluation (refer to section 3.7.3.3.4).
   d. Individual teacher evaluation of the e-learning software (refer to section 3.7.3.3.5).
   e. Group debrief meeting on evaluation results (refer to section 3.7.3.3.6).
   f. Focus groups to secure research findings (refer to section 3.7.3.3.7).
5. Merge and interpret results from different research strands.

3.7.3.3.1 Phase 3- E-learning Evaluation Protocol

The Phase 3 e-learning evaluation protocol was developed in response to the Phase2–Cycle2 feedback from the education experts, the findings from the pilot evaluation of Level-1 and Level-2 software, and a focused literature review on heuristic evaluation protocols. The evaluation protocol was drafted based on GCSE Computer Science E-Learning Pedagogy v1.7b(CLEAR).

The evaluation protocol describes both the evaluation process and acts as the evaluation review template in which evaluators provide their feedback.

3.7.3.3.2 Evaluation of the E-learning Evaluation Protocol by Education Experts

The composition of the evaluation group that evaluated the e-learning evaluation protocol in Phase 3 is outlined in section 3.7.3.2.1.This feedback was provided in writing as inline comments within the document; where necessary, the written comments were followed by one-to-one discussions for further explanation.

The evaluation feedback was minimal and incorporated into the final version of the e-learning evaluation protocol. This education expert feedback on the e-learning evaluation protocol is summarised in section 6.7.3.1. For reference, the final version of the e-learning evaluation protocol (based on Phase 3 findings), is included in Vol 3 Appendix N.

3.7.3.3.3 Train Teachers on the Pedagogical Heuristics

The workshop on the design and evaluation of e-learning software commenced with an introductory session, followed by training on the pedagogical heuristics. These sessions were led by the researcher and guided by the following presentations:

1. **Workshop Introduction:** A 6 slide presentation that outlined: the research foundations of the workshop, the aims of the workshop, the benefits to the attendees, and the workshop agenda.

2. **Summary of the Pedagogical Heuristics:** A 53 slide presentation that outlined: what pedagogical heuristics are, their interrelationship, their educational benefits, and a summary of each of the 21 heuristics (40 including sub-heuristics).

3.7.3.3.4 Outline the Procedure for the E-learning Evaluation

After the teachers were trained on the pedagogical heuristics, they received training on the e-learning evaluation protocol. This session was guided by the following presentation:

- **Summary of e-learning evaluation protocol:** A 15 slide presentation that outlined: what educational value is, the necessary teacher expertise for the evaluation, why groups are best for evaluations, the evaluation procedure, how to provide evaluation results, the response scales, the e-learning software being evaluated, and the educational setting acting as the basis of the evaluation.

3.7.3.3.5 Individual Teacher Evaluation of the E-learning Software

An integral part of the e-learning evaluation protocol is the hands-on evaluation of the software. After receiving training on both the pedagogical heuristics and the evaluation procedures, the teachers were given access to the Level 3 Orange - Algorithms and Flowcharts V0.3 software to undertake the evaluation. The teachers accessed the software via SCORMCloud; due to time limitations, they had approximately 1 hour and 15 minutes to evaluate the software and record their responses in the online evaluation response instrument.

In normal circumstances, the e-learning evaluation protocol document is also a feedback template that allows evaluators to record their evaluation results in a structured and consistent manner. However, due to the time constraints imposed by the workshop, a mechanism was necessary to consolidate the evaluation results from all group members within a 15-minute window, before the group debrief sessions. In response to this constraint, an online survey instrument was developed and used to collect the respondents' quantitative feedback on the level of importance of each heuristic and learning objective, and the level of support the software gave to each heuristic and learning objective. For reference, the Evaluation Response Collection Instrument is included in Vol 3 Appendix P.

The researcher was present throughout the evaluation activity and gave minimal guidance to ensure the teachers could progress with the evaluation in the time allotted. There was no disruption to the activity.

3.7.3.3.6 Group Debrief Meeting on Evaluation Results

The overriding objective of the evaluation process is a single evaluation report that fairly represents the aggregated findings of the set of evaluators. In support of this objective, a debrief session was run by an unbiased facilitator whose role was to encourage effective discussion, and accurately document the group's consensus in the final report. Specifically, the aim was to reach a consensus in the areas of:

1. Quantitative evaluation of the importance of applicable heuristics and learning objectives,

2. Quantitative evaluation of the level of support the software provides to the applicable heuristics and learning objectives, and
3. Qualitative comments on pedagogical issues and improvement recommendations.

After the group report was finalised, it was then shared with the evaluators either for their feedback or their confirmation that it was accurate.

As discussed in 3.7.3.3.5, prior to the group debrief session, all the individual evaluation responses were consolidated into summary snapshots for each learning objective and heuristic, which in turn were used to structure and guide the debrief session.

It is not a mandatory pre-requisite for the debrief session, but in support of the research efforts:

1. The Group 1 debrief session was recorded on video and later transcribed.
2. The Group 2 debrief session was recorded in audio and later transcribed, although due to poor audio quality, the recording has some intermittent sections which could not be transcribed.

Standard procedures for the secure handling of audio and video material were followed.

3.7.3.3.7 Focus Group

Although not part of the evaluation process, at the end of the workshop two focus groups were planned in which the teacher participants were to have a facilitated discussion to give their feedback on the day. Specifically, to give their feedback on their personal and their school's experience with the use and evaluation of e-learning software, and feedback on the pedagogical heuristics and the e-learning evaluation process they had used.

To ensure consistency between both focus groups, a set of guiding questions was developed and used. The questions were created by the researcher and reviewed by an education expert prior to finalisation and usage. For reference, the focus group guidance questions are included in Vol 3 Appendix R.

The planned duration of the focus groups was one hour; however due to an overrun during the day, Group-2 completed the focus group in 20 minutes, and for Group-1, it was decided to continue with the evaluation debrief session. The teachers in Group-1 agreed to answer the focus group questions from home using an alternate survey instrument that contained the same guidance questions.

Five teachers were planned to attend the Group-1 focus group, of which four responded on the alternate survey instrument. Five teachers were planned to attend the Group-2 focus group; all the teachers attended, but one teacher had to leave early (after the first question) from the discussion.

The Group-2 focus group was recorded in audio and later transcribed, although due to poor audio quality the recording has some intermittent sections which could not be transcribed. Standard processes for the secure handling of audio and video material were followed.

3.7.3.4 Data Collection, Analysis and Reporting

The Phase 3 research data collected in relation to the e-learning evaluation protocol is primarily qualitative in nature. Observations from the Group-1 debrief session, transcripts from the Group 2 debrief session and focus group, and the Group-1 survey response were all analysed thematically, and triangulated to give a holistic interpretation.

Quantitative findings from the Evaluation Response Collection Instrument are compared with the final debrief results and compared between Group 1 and Group 2 to give indicators on the validity and reliability of the evaluation protocol.

These findings are presented in summary form in section 6.7.3.2 and full form in Vol 2 Appendix C, and were used to update the final version of the e-learning evaluation protocol.

3.8 Chapter Summary

This chapter outlines the magnitude and interconnectedness of the mixed methods exploratory design used in this research. It is a roadmap to the research activities, and gives reference in the appendices to key instruments and materials used in the research. The following were discussed in detail:

1. The theoretical foundations underpinning the choice of research methods,
2. Discussion of the exploratory mixed methods design, which is divided into three phases, each with a different qualitative-quantitative mix:
    a. Phase 1: Pilot,
    b. Phase 2: Elaboration via Action Research,
    c. Phase 3: Final experiment to confirm the qualitative findings of Phase 1 and 2, and generalise to the wider GCSE Computer Science population.
3. The use of a convergent parallel design (triangulation design) for each of the above phases,
4. Aligning research controls to the mixed methods design, by incorporating controls to ensure validity and reliability, but additionally implementing procedures for the parallel qualitative concept of trustworthiness and its underlying criteria of credibility, transferability, dependability and confirmability,
5. A breakdown of the teacher, student and education expert participants used in each phase and cycle of the study,
6. The apparatus used in each phase and cycle of the study, and a focus on the validity and reliability of key instruments such as the VARK instrument, the survey instrument, the IMMS instrument and the Pre-, Post-Test,
7. The procedures used in each phase and cycle of the study,
8. The data collection, analysis and reporting used in each phase and cycle of the study, and the approaches to triangulate between the different strands of research data in each phase,
9. A detailed focus on the quantitative analysis used in Phase 3 and reference to the Phase 3 codebook.

Finally, there is a compartmentalised discussion of the research methods for the development of the e-learning evaluation protocol.

4 SYNTHESIS OF THE E-LEARNING PEDAGOGY

4.1 Chapter Brief

This chapter focuses on the synthesis of the e-learning pedagogy; previously, section 2.3.2 and 2.3.3 outlined the need to focus on pedagogy for e-learning software and the limitations of existing research. Section 2.4 discussed what learning theories are, and provided a summary review of the learning theories and other inputs that are at the foundation of this e-learning pedagogy. These are: constructivism, social constructivism, collaborative learning, connectivism, VARK learning styles, ARCS motivational design, cognitive load theory, gamification, and computational thinking. This chapter builds on that material to discuss the underlying characteristics of the pedagogy and describe the individual pedagogical heuristics.

4.2 Versions of the E-learning Pedagogy

As discussed in Chapter Three, the e-learning pedagogy was iteratively developed and refined through the three phases of this research study. Five versions of the e-learning pedagogy were developed and released; these are outlined in Table 10.

Phase	Date	Pedagogy	Appendices
Phase 1	04/02/2015	GCSE Computer Science E-Learning Pedagogy v0.7	Included in pedagogy document.
Phase 2-Cycle 1	01/12/2015	GCSE Computer Science E-Learning Pedagogy v1.2	Included in pedagogy document.
Phase 2-Cycle 2	05/06/2016	GCSE Computer Science E-Learning Pedagogy v1.5	Computer Science E-Learning Pedagogy Appendices v0.3
Phase 3	04/10/2016	GCSE Computer Science E-Learning Pedagogy v1.7b(CLEAR)	Computer Science E-Learning Pedagogy Appendices v0.4 (CLEAR)
Final	26/03/2018	GCSE Computer Science E-Learning Pedagogy v1.8	Computer Science E-Learning Pedagogy Appendices v0.5

Table 10: Five versions of the e-learning pedagogy

These pedagogy releases form the basis of the evaluation results presented in section 6.4.

4.3 Intended Audience and Usage

As discussed in Chapter Two, this pedagogy builds on the increasing integration of technology-enhanced learning in education by supporting the use of e-learning software within a high-school environment. The research aims to support high-school computing with a comprehensive set of pedagogical heuristics that can be used by teachers or other educators in either the design or evaluation of e-learning software for computer science.

The learning theories discussed in this pedagogy are not focused on any specific subject discipline; however, holistically the focus of the pedagogy is towards computer science. It follows that, overall, the pedagogy is designed to be more appropriate for computer science or other Science, Technology, Engineering and Mathematics (STEM) subjects, and therefore potentially less appropriate for other subject areas such as languages, arts, social studies and the humanities. These heuristics supplement existing literature on instructional design and extend existing e-learning heuristics since these heuristics focus more tightly and in-depth on pedagogy rather than usability. It is important to consider that:

1. The heuristics are not intended to instruct good pedagogy to teachers.
2. The heuristics are offered as guidance to teachers and instructional designers in the design or selection of e-learning software appropriate for high-school computer science education.
3. The heuristics are not intended to be implemented as a mandatory checklist.
4. The heuristics are intended to be used as a toolset from which the correct tools are selected by a teacher or instructional designer based on the specific learning material, intended audience and intended learning objectives.
5. Although not explicitly considered in this pedagogy, usability is recognised to be critical to e-learning software, and is a mandatory prerequisite to be considered in conjunction with pedagogical quality.

4.4 Pedagogical Coverage

The overriding objective of this pedagogy is to holistically consolidate and condense the essence of e-learning pedagogy in a manner accessible to the teacher audience. The first key factor in this objective is to comprehensively embody the full learning process. In consideration of Illeris' framework for learning (section 2.4.2), Figure 15 maps the various learning theories to their primary area of educational influence. It is evident that there is comprehensive coverage of the two processes of external interaction and an internal acquisition, and the three dimensions of content, incentive and environment.

It should also be noted that these theories are taken as a theoretical foundation for the heuristics and not prescribed in their extreme form. There is a concerted effort to find commonality and overlap between the theories so as to develop a cohesive set of pedagogical heuristics that can be used holistically together with minimal conflict.

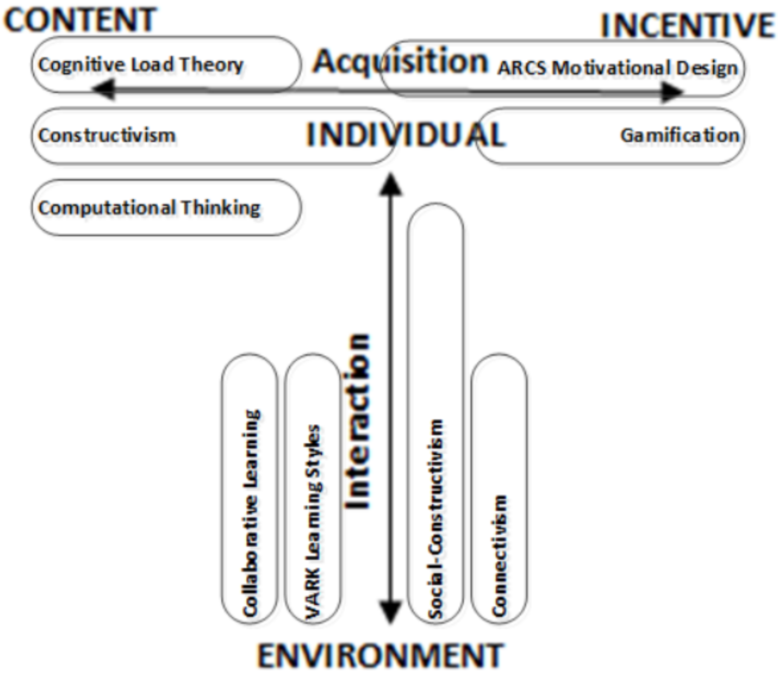


Figure 15: Mapping of learning theories to Illeris' three dimensions of learning

4.5 A Non-Prescriptive Pedagogy

The proposed pedagogy avoids being reductionist and prescriptive; it is intended to be a toolset by which teachers and instructional designers can use the tools (heuristics) based on their judgement and in consideration of the educational setting. However, such judgement must be adequately informed; it is for this reason that the pedagogy gives detailed information on design and evaluation criteria, potential benefits, how the heuristics interrelate, and potential challenges in implementation. Each heuristic contains the following information:

- **ID:** A unique heuristic identification number.
- **Title:** The title of the heuristic.
- **Description:** A brief description that summarises the heuristic.
- **Learning Theory:** An indicator of whether the heuristic has been derived from a specific learning theory.
- **Pedagogical Area:** An indicator of which area of instruction the heuristic relates to.
- **Design and Evaluation Criteria:** A set of criteria that can be used either as design guidelines to implement the heuristic in e-learning software, or as evaluation guidelines to evaluate the adherence of existing e-learning software to the heuristic.
- **Education Benefits:** Outline of the potential benefits associated with the successful implementation of this heuristic.
- **Potential Challenges:** Outline of some of the potential challenges that could be faced when implementing the heuristic.
- **Related Heuristics:** Outline of other heuristics that interrelate with this heuristic, either in positive support or potentially in contradiction.

The final e-learning pedagogy is included in Vol 2 Appendix D; however, for easy reference, below is an example of how each heuristic is documented:

ID	Heuristic Title:		
1	Use authentic educational material, examples and activities.		
Learning Theory:	Constructivism	**Pedagogical Area:**	Authenticity

Description:

Authentic learning represents learning material in a manner that focuses on the context of when the knowledge and skills will be used. It allows the learner a closer tie to reality and a better understanding of the relevancy of the material and its true value. This in turn leads learners to take greater ownership of their learning, achieve a deeper understanding, and increase knowledge transfer to the real-world.

Design and Evaluation Criteria:

The learning material and activities in the e-learning software and associated CLE should reflect a meaningful subset of the following characteristics of authenticity:

1. **Provide contextual authenticity by:**
   a. Exploring the real-world dimensions of a task,
   b. Providing realistic background information that surrounds the learning or problem,
   c. Simulating real-life complexities and occurrences, or
   d. Using practices and tools used by experts in the field under study.
2. **Provide cognitive authenticity by engaging the learner in activities which present the same type of intellectual challenges as those in the real-world.**
3. **Provide activities that are intrinsically motivating, that learners are encouraged to solve.**
4. **Provide learning and activities that are personally relevant or interesting to the learner.**
5. **Provide learning and activities that are not artificially constrained.**
6. **Provide the technical affordance for teachers and instructional designers to easily change text and visual learning material to be more authentic and personalised to their students.**

Educational Benefits:

The use of authentic educational material, examples and activities leads to the following education benefits:

1. Learners more successfully assimilate / accommodate the learning into their own mental models (schemas).
2. There is an increased likelihood that learners will take ownership of their learning or the resolution of a problem activity.
3. Learners more effectively grasp the meaning and value of the learning material and the context in which the knowledge or skills can be used in the real-world.

4. Learners are more motivated by authentic or personally relevant learning material.
5. Authentic learning enables deeper learning and improved far transfer.

Potential Challenges:

It is important that authentic learning ties back to reality; but it should not model reality in an ultra-realistic manner that overwhelms the learner or constrains the learning to a narrow context. Instead, it is better to give greater focus to cognitive authenticity.

Although authentic learning most intuitively fits into whole-task instruction, special care should still be given to examples and problems within part-task instruction to maintain a reasonable level of authenticity where possible.

Related Heuristics:

Authentic learning offers strong support in the following areas:

- Ensuring the currency of learning material (Heuristic 1.1)
- Reflective practice and making expert and learner thinking processes explicit (Heuristics 2, 3)
- Integrating learning into long term memory (Heuristic 5)
- Problem-based learning and computational thinking (Heuristics 4, 4.1, 6, 6.1, 6.2)
- Practice activities and kinaesthetic learning (Heuristics 7, 16.4)
- Social and collaborative learning, situated learning through mobile devices and networked learning (Heuristic 9, 11, 11.1, 12)
- Learner motivation and gamification (Heuristics 13, 14, 14.2, 14.4, 15, 15.1)

However, it is important to consider that authentic learning can increase cognitive load and conflict with heuristics 18 and 19, relating to the optimisation of essential processing, and focusing only on learning material that directly supports learning objectives.

With reference to Table 11, the final e-learning pedagogy contains 21 heuristics, and an additional 19 sub-heuristics.

ID	Heuristic Title
1	Use authentic educational material, examples and activities.
1.1	Ensure the currency of learning material.
2	Prompt reflective practice to support learning.
3	Make expert and learner thinking processes explicit.
4	Use problem-based learning (PBL) to facilitate learning.
4.1	Use worked examples to support problem-based learning.

ID	Heuristic Title
5	Integrate learning into long-term memory by using authentic examples, and non-trivial practice and problems.
6	Support problem-solving through computational thinking.
6.1	Build a foundation for computational thinking.
6.2	Exemplify computational thinking in problem-solving activities.
7	Distribute well-designed practice activities across the lesson to support learning.
7.1	Provide explanatory feedback to practice activities to promote learning.
8	Provide scaffolding to advance learning progress.
9	Use social-interaction to increase learning and promote higher-order thinking.
10	Engage learners in a challenge; target learning towards the zone of proximal development (ZPD).
11	Use collaborative learning activities.
11.1	Support collaborative and situated learning via mobile devices.
12	Develop and nurture networks to support learning.
13	Use constructivist approaches to increase intrinsic motivation in the learner.
14	Use the concepts of Attention, Relevance, Confidence and Satisfaction (ARCS) to attain and sustain learner motivation.
14.1	Use "Attention" grabbing strategies to increase learner motivation.
14.2	Explain the "Relevance" of the learning material to increase motivation.
14.3	Build "Confidence" to increase learner motivation.
14.4	Build "Satisfaction" to increase learner motivation.
15	Use gamification to increase motivation and learning performance.
15.1	Integrate gamification elements tightly within existing learning processes.
15.2	Build extrinsic gamification elements on top of existing learning processes.
16	Use multi-modal learning approaches.
16.1	Support visual modal preference.
16.2	Support aural modal preference.
16.3	Support read-write modal preference.
16.4	Support kinaesthetic modal preference.
17	Integrate words and graphics together, instead of words alone.
17.1	Apply contiguity by aligning words (audio or screen text) with corresponding graphics.
17.2	Representing words as audio, on-screen text or both.
18	Avoid adding learning content that does not directly support your instructional goal.
19	Optimise essential processing by segmenting learning material and providing pre-training.
20	Use a conversational style in screen text and audio narration.
21	Provide restricted navigational control in the e-learning software.
21.1	Provide consistent navigational elements and signposts for learning.

Table 11: Final set of e-learning pedagogical heuristics.

4.6 Further Support for the Selection and Usage of Heuristics

Considering the substantial number of heuristics and sub-heuristics, and the level of detail of each heuristic, the teacher audience was given further support in the selection and usage of the heuristics by the provision of summary visual material on how heuristics interrelate, and their potential benefits and dis-benefits. This is facilitated via an:

1. Educational Benefits Matrix
2. Heuristics Interrelationship Map
3. Heuristics Interrelationship Matrix

4.6.1 Educational Benefits Matrix

The educational benefits matrix provided in Table 12 indicates the learning benefits that can potentially be achieved by the successful implementation of each heuristic. This matrix is offered as a high-level visual guidance to teachers and instructional designers on what heuristics can be focused on when targeting certain educational benefits. It should be noted that implementation of a heuristic does not guarantee that the educational benefit will be realised, and does not preclude that other educational benefits will be realised. The educational benefits are categorised into five main areas:

1. **Learning Performance (Surface Learning):** Learning performance is an immediate measure of the students' ability to recall learning material and successfully pass assessments closely linked to that learning material. In the context of this research, this relates to the students' ability to pass GCSE Computing assessments and exams.
2. **Deep Learning:** As opposed to surface learning, in which learning material is typically passively memorised with a primary aim of passing assessments, deep learning is learning where there is a vigorous interaction with the learning material to truly understand it and integrate it with previous experience and knowledge. Meaning it is integrated into existing mental schemas in the learner's long-term memory.
3. **Far Transfer / Higher Order Thinking:** Far transfer is the application of skills and knowledge learned in one situation to a different situation. It builds upon deep learning, and requires learners to adjust the underlying principles they have learnt for use in a new scenario or new problem. It requires higher order thinking, which in terms of Bloom's revised taxonomy (Krathwohl 2002) includes analysing, evaluating and creating.
4. **Motivation:** Motivation is a theoretical construct used to explain the reason(s) one has for acting or behaving in a particular way, and relates to the general desire or willingness of someone to do something. In the context of this research, it focuses on the incentive (motivation) to devote mental energy to learning.
5. **Cognitive Load:** At any given time, humans can actively process only limited information; material that exceeds this threshold may enter working memory but will not be processed and encoded into long term memory. It is therefore important that the cognitive processes that

organise incoming information into logical structures, and integrate it with existing knowledge, are supported by optimising the learning material to reduce cognitive load.

LEGEND: Strong Benefit (green); Moderate Benefit (yellow); No Benefit (white); Counteracts Benefit (red)

ID	Heuristic Title	Learning Performance	Deep Learning	Far Transfer / Higher Order Thinking	Increased Motivation	Reduce Cognitive Load
1	Use authentic educational material, examples and activities.	Strong Benefit	Strong Benefit	Strong Benefit	Strong Benefit	Counteracts Benefit
1.1	Ensure the currency of learning material.	Moderate Benefit	Moderate Benefit	Moderate Benefit	Strong Benefit	Counteracts Benefit
2	Prompt reflective practice to support learning.	Strong Benefit	Strong Benefit	Strong Benefit	Strong Benefit	No Benefit
3	Make expert and learner thinking processes explicit.	Strong Benefit	Strong Benefit	Strong Benefit	No Benefit	Counteracts Benefit
4	Use problem based learning (PBL) to facilitate learning.	Strong Benefit	Strong Benefit	Strong Benefit	Strong Benefit	Counteracts Benefit
4.1	Use worked examples to support problem based learning.	Strong Benefit	Strong Benefit	Strong Benefit	Strong Benefit	Strong Benefit
5	Integrate learning into long-term memory by using authentic examples, and non-trivial practice and problems.	Strong Benefit	Strong Benefit	Strong Benefit	Strong Benefit	Counteracts Benefit
6	Support problem solving through Computational Thinking.	Moderate Benefit	Strong Benefit	Strong Benefit	Moderate Benefit	No Benefit
6.1	Build a foundation for Computational Thinking.	Moderate Benefit	Strong Benefit	Strong Benefit	No Benefit	Strong Benefit
6.2	Exemplify Computational Thinking in problem solving activities.	Moderate Benefit	Strong Benefit	Strong Benefit	Strong Benefit	Counteracts Benefit
7	Distribute well-designed practice activities across the lesson to support learning.	Strong Benefit	Strong Benefit	Moderate Benefit	Strong Benefit	No Benefit
7.1	Provide explanatory feedback to practice activities to promote learning.	Strong Benefit	Strong Benefit	Moderate Benefit	Strong Benefit	Moderate Benefit
8	Provide scaffolding to advance learning progress.	Strong Benefit	Strong Benefit	Moderate Benefit	Strong Benefit	Strong Benefit
9	Use social-interaction to increase learning and promote higher-order thinking.	Moderate Benefit	Strong Benefit	Moderate Benefit	Strong Benefit	No Benefit
10	(ZPD).	Strong Benefit	Strong Benefit	Moderate Benefit	No Benefit	No Benefit
11	Use collaborative learning activities.	Strong Benefit	Strong Benefit	Moderate Benefit	Strong Benefit	No Benefit
11.1	Support collaborative and situated learning via mobile devices.	Moderate Benefit	Moderate Benefit	Moderate Benefit	Strong Benefit	Strong Benefit
12	Develop and nurture networks to support learning.	Strong Benefit	Strong Benefit	Strong Benefit	Strong Benefit	Counteracts Benefit
13	Use constructivist approaches to increase intrinsic motivation in the learner.	Strong Benefit	Strong Benefit	Strong Benefit	Strong Benefit	Counteracts Benefit
14	Use the concepts of Attention, Relevance, Confidence and Satisfaction (ARCS) to attain and sustain learner motivation.	Strong Benefit	Strong Benefit	Moderate Benefit	Strong Benefit	Counteracts Benefit
14.1	Use "Attention" grabbing strategies to increase learner motivation.	Strong Benefit	Moderate Benefit	Moderate Benefit	Strong Benefit	Counteracts Benefit
14.2	Explain the "Relevance" of the learning material to increase motivation.	Strong Benefit	Strong Benefit	Moderate Benefit	Strong Benefit	Counteracts Benefit
14.3	Build "Confidence" to increase learner motivation.	Strong Benefit	Strong Benefit	Moderate Benefit	Strong Benefit	No Benefit
14.4	Build "Satisfaction" to increase learner motivation.	Strong Benefit	Strong Benefit	Strong Benefit	Strong Benefit	Counteracts Benefit
15	Use gamification to increase motivation and learning performance.	Strong Benefit	Moderate Benefit	Moderate Benefit	Strong Benefit	Counteracts Benefit
15.1	Integrate gamification elements tightly within existing learning processes.	Strong Benefit	Strong Benefit	Strong Benefit	Strong Benefit	Counteracts Benefit
15.2	Build extrinsic gamification elements on top of existing learning processes.	Strong Benefit	No Benefit	No Benefit	Strong Benefit	No Benefit
16	Use multi-modal learning approaches.	Strong Benefit	Strong Benefit	Moderate Benefit	Strong Benefit	Counteracts Benefit
16.1	Support visual modal preference.	Strong Benefit	Strong Benefit	Moderate Benefit	Strong Benefit	Strong Benefit
16.2	Support aural modal preference.	Strong Benefit	Moderate Benefit	Moderate Benefit	Strong Benefit	Counteracts Benefit
16.3	Support read-write modal preference.	Strong Benefit	Moderate Benefit	Moderate Benefit	Strong Benefit	Counteracts Benefit
16.4	Support kinaesthetic modal preference.	Strong Benefit	Strong Benefit	Moderate Benefit	Strong Benefit	Counteracts Benefit
17	Integrate words and graphics together, instead of words alone.	Strong Benefit	Strong Benefit	Moderate Benefit	Moderate Benefit	Strong Benefit
17.1	Apply contiguity by aligning words (audio or screen text) with corresponding graphics.	Strong Benefit	Strong Benefit	Moderate Benefit	Moderate Benefit	Strong Benefit
17.2	Representing words as audio, on-screen text or both.	Strong Benefit	Strong Benefit	Moderate Benefit	Moderate Benefit	Strong Benefit
18	Avoid adding learning content that does not directly support your instructional goal.	Strong Benefit	Counteracts Benefit	Counteracts Benefit	Counteracts Benefit	Strong Benefit
19	Optimise essential processing by segmenting learning material and providing pre-training.	Strong Benefit	Moderate Benefit	Counteracts Benefit	No Benefit	Strong Benefit
20	Use a conversational style in screen text and audio narration.	Strong Benefit	Moderate Benefit	Moderate Benefit	Strong Benefit	Moderate Benefit
21	Provide restricted navigational control in the E-Learning software.	Strong Benefit	Moderate Benefit	Moderate Benefit	No Benefit	Strong Benefit
21.1	Provide consistent navigational elements and signposts for learning.	Strong Benefit	Moderate Benefit	Moderate Benefit	No Benefit	Strong Benefit

Table 12: Educational benefits matrix

4.6.2 Heuristic Interrelationships

Teachers are further supported in their selection and usage of heuristics via a clear understanding of how the heuristics interrelate and reinforce each other and, in some cases, how some heuristics counteract each other. This is achieved at a detailed level by the 'Related Heuristics' section of each heuristic, and is reflected in a more accessible format via the interrelationship map. With reference to Figure 17, the interrelationship map provides a high-level indicator of some of the key relationships between pedagogical areas and heuristics. Heuristics that are highly related are grouped into boxes reflecting a pedagogical area. Boxes that are enclosed or overlap reflect a strong positive relationship. Green relationship lines reflect a potentially positive relationship between pedagogical areas or specific heuristics. Red relationship lines reflect a potentially counteractive relationship between pedagogical areas or specific heuristics.

Heuristic interrelationships are visually represented in more detail by the interrelationship matrix which maps all heuristics against each other and represents relationships according to the colour coded legend in Figure 16.

Figure 16: Legend for interrelationship matrix

Due to the unavoidable size (40 x 40 heuristics) and complexity of this matrix, it is more effectively used as a reference resource. The interrelationship matrix is included for reference in Vol 3 Appendix X.

It should be noted that the pedagogy and sub-deliverables, such as the educational benefits matrix, interrelationship map and interrelationship matrix, distil an extensive literature review on e-learning pedagogy, but by definition this is bounded, and does not guarantee educational outcomes. It offers guidance and recommendation on what heuristics, if employed correctly, give the best likelihood of achieving the targeted educational outcomes.

As summary tools, it should also be noted that, if there is any lack of clarity or seemingly counterintuitive information reflected in the educational benefits matrix, interrelationship map or interrelationship matrix, then reference should be made to the specific section of the heuristic description, which provides detailed explanatory information.

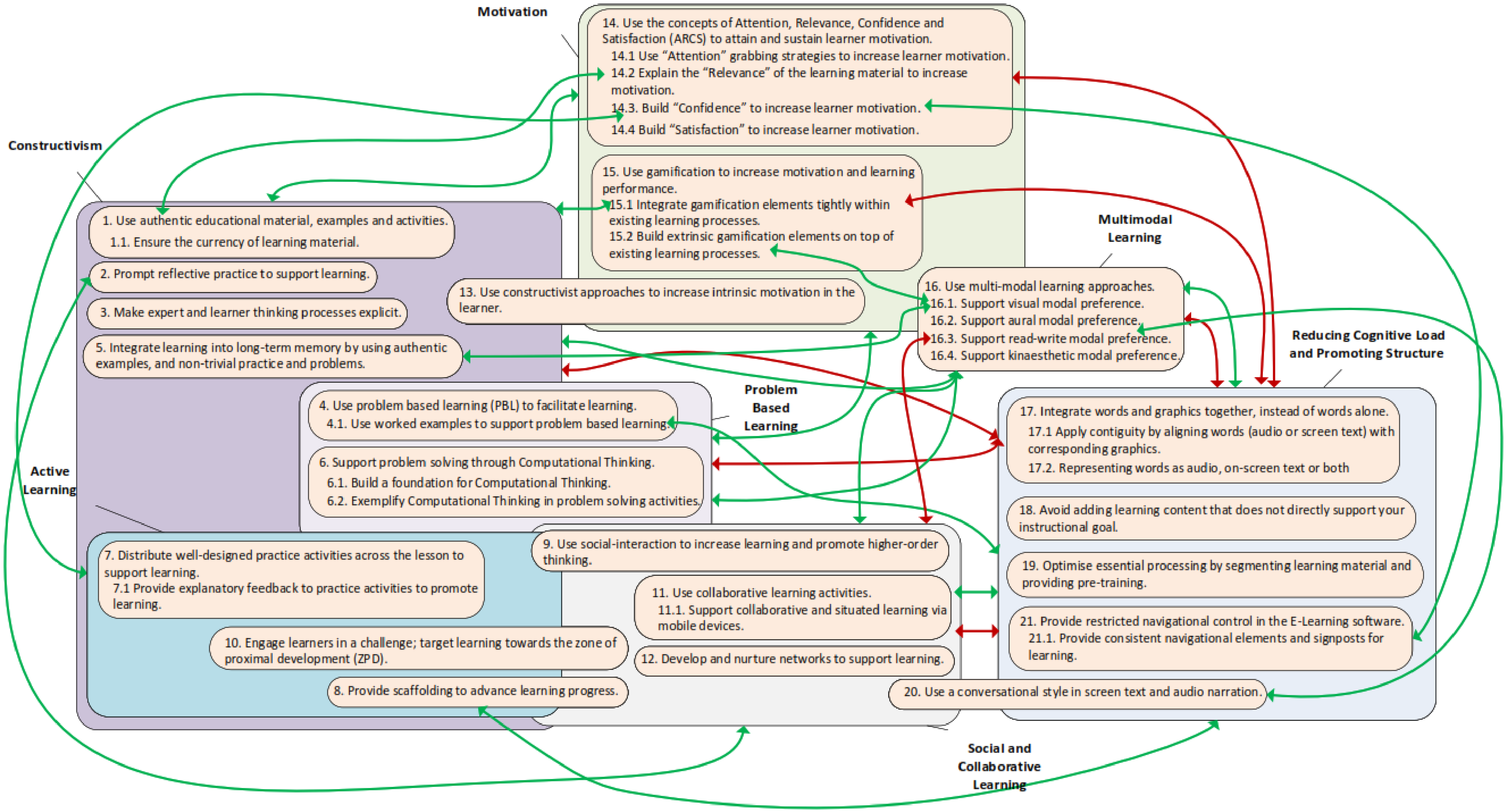


Figure 17: Heuristics interrelationship map

4.7 Discussion of Heuristics

The remainder of this chapter builds on the literature review in section 2.4 to provide an outline of the learning theories and their specific influence on the pedagogical heuristics. As discussed in the previous section (4.6.2) the interrelationships between heuristics is a significant area which is discussed in detail in the pedagogy. However, for brevity it is not described in detail in this chapter, it is described in detail for each heuristic in Vol 2 Appendix D (section 9) and can be viewed in summary form in Figure 17 (previous page).

4.7.1 Constructivism

Building on the review of constructivism presented in section 2.4.3, this section further discusses constructivist principles and elaborates on how they are distilled into the e-learning heuristics outlined in Table 13.

ID	Heuristic
1	Use authentic educational material, examples and activities.
2	Prompt reflective practice to support learning.
4	Use problem-based learning (PBL) to facilitate learning.
4.1	Use worked examples to support problem-based learning.
5	Integrate learning into long-term memory by using authentic examples, and non-trivial practice and problems.
7	Distribute well-designed practice activities across the lesson to support learning.
7.1	Provide explanatory feedback to practice activities to promote learning.
13	Use constructivist approaches to increase intrinsic motivation in the learner.

Table 13: E-learning heuristics based on constructivism

4.7.1.1 Heuristic 1: Use Authentic Educational Material, Examples and Activities

Authentic learning represents learning material in a manner that focuses on the context of when the knowledge and skills will be used. It allows the learner a closer tie to reality and a better understanding of the relevance of the material and its true value. This in turn leads learners to take greater ownership of their learning, a deeper understanding, and increased knowledge transfer to the real-world.

As outlined by Jonassen (1999, p.221) *"Nearly every conception of constructivist learning recommends engaging learners in solving authentic problems."* However, in the context of this study, the following authors (Jonassen 1999; Jonassen & Hung 2008; Fadel & Lemke 2008; Karagiorgi & Symeou 2005; Hadjerrouit 2005; Squires & Preece 1999; Gilbert et al. 2007; Jang 2009; Brooks & Brooks 1999) express support for authentic learning. Additionally, the synthesis of their work gives direction that authentic learning and activities should reflect several of the following characteristics: contextual authenticity, cognitive authenticity, intrinsically motivational, personally relevant or interesting, and not artificially constrained or abstract. Additionally, Jonassen (1999) cautions that it is important that authentic learning ties back to reality, but it should not model reality in an ultra-realistic manner that overwhelms the learner or constrains the learning to a narrow context.

The use of authentic learning most notably leads to the more successful integration of learning into mental models, enabling deeper learning and improved far transfer. Furthermore, authentic or personally relevant learning material is intrinsically motivational to the learner: increasing the likelihood that learners will take ownership of their learning, and more effectively grasp the meaning and value of the learning material and the context in which the knowledge or skills can be used in the real-world. However, it is important to consider that authentic learning can increase cognitive load and conflict with the optimisation of essential processing and focusing only on learning material that directly supports learning objectives.

4.7.1.2 Heuristic 2: Prompt Reflective Practice to Support Learning

Reflective practice is the careful contemplation of one's own thinking processes, actions and beliefs that in turn support further learning; it is an important part of the constructivist knowledge-building process. Learners typically do not reflect on their learning unless guided to do so; therefore, the e-learning software and CLE should provide reflective prompts and associated activities. These typically take the form of questions or discussions that stimulate the imagination, theory creation, further thinking, further questions or meta-cognitive thinking.

As discussed in section 2.4.3, constructivist principles focus less on transferring information to learners and more on facilitating their knowledge construction; the latter is greatly supported by the encouragement of reflective practices. Jonassen (1999) recommends reflection on the monitoring and analysis of learning performance (strategies and progress) and learning comprehension.

The following authors (Humphreys et al. 1997; Brooks & Brooks 1999; Jonassen 1999; Aleven & Koedinger 2002; Mayer et al. 2003; Slack et al. 2003; Moreno & Mayer 2005; Hubbs & Brand 2005; Barbour & Rich 2007; Moreno & Mayer 2007; Williams et al. 2008; Chen et al. 2009; Denton 2012) express support for reflective practice. Additionally, the synthesis of their work gives guidance that reflective practice should incorporate several of the following characteristics: provide reflective prompts within the learning material; include these prompts when students are challenged in accommodating new learning; reflective activities should lead to further iterations of activity, feedback and observation based on the reflection; provide learners with collaborative reflection activities focused on recent learning events; and involve learners in providing peer feedback or assessment.

Implementation of the above reflective practices can potentially lead to the following learning benefits: improved learning performance; deeper understanding and integration into mental models; and increased mental flexibility, thereby improving far transfer. In addition, collaborative peer reflection, in particular in a peer feedback context, improves learning motivation and learning performance.

4.7.1.3 Heuristic 4: Use Problem-based Learning (PBL) to Facilitate Learning

Problem-based learning, in contrast to part-task instruction, focuses on the bigger picture and begins with an authentic problem or work assignment which drives the learning process in trying to solve the problem. Working on the problem takes the form of a guided discovery that integrates into the process the necessary knowledge and skills to solve the problem, and arguably results in a richer, more challenging learning experience. PBL has a strong foundation in medical teaching (Jonassen & Hung 2008; Koh et al. 2008; Schmidt et al. 2009), but has also garnered wider support (Jonassen 1999; Jonassen & Hung 2008; Brooks & Brooks 1999; Buzzetto-more & Alade 2006; Lim et al. 2009; Liu et al. 2011; Melero et al. 2012; Nasr & Ramadan 2008) in other educational disciplines. Williams et al. (2008, p.327), discuss PBL, in a high-school computing context:

"The conclusion of the project evaluation was that a problem-based learning methodology is appropriate for use in technology education, both to achieve the goals of technology education and to give students experience in a realistic group work environment."

Additionally, Zapalska and Brozik (2006) emphasise that the active learning inherent in PBL is aligned with the multi-modal learning styles defined by the VARK method (which is also a central theme within the e-learning pedagogy defined in this study).

Considering the findings of (Lebow 1993; Jonassen 1999; Jonassen & Hung 2008; Buzzetto-More & Alade 2006; Nasr & Ramadan 2008; Williams et al. 2008; Liu et al. 2011; Clark & Mayer 2011; Melero et al. 2012; Lim et al. 2009; Sweller et al. 1998; Schraw et al. 2006; Moreno & Mayer 2005), the following guidelines for PBL are identified:

1. **Select an appropriately complex and ill-structured problem** that considers: learning objectives, learner ability, subject knowledge, and appropriate challenge, without creating cognitive overload;
2. **Provide a suitably rich problem representation that describes the problem and its context**, without being overly prescriptive and reducing the learner's need to think;
3. **Include multiple problems / case studies to initiate the learning process** and give an authentic context; this supports learners in building the necessary mental models for the current problem, and in far transfer learning;
4. **Integrate a problem-based learning flow to guide the students** in the approach to tackle the problem; such macro-scaffolding reduces the cognitive load on the learners. Depending on the size and complexity of the problem, an abridged version of the PBL flow can be undertaken in iterative cycles;
5. **Support and educate students in the metacognitive processes** needed in problem-based learning. Either teachers or the e-learning software needs to educate and support learners in the relevant metacognitive processes that enable the planning, monitoring and delivery of the problem solution;

6. **Provide a collaborative environment to support the social interactivity** inherent in problem-solving. PBL is inherently based on social theories of learning and on the interaction of learners in negotiating a solution to the problem. Therefore, in the context of e-learning, appropriate collaborative tools should be put in place; and
7. **Provide a Problem Manipulation Environment**. The kind of mindful activity necessary in PBL requires a problem manipulation environment which supports the learners in investigating, hypothesising and testing their hypothesis.

The appropriate implementation of such guidelines can potentially lead to the following learning benefits typically associated with PBL (Jonassen & Hung 2008; Koh et al. 2008; Schmidt et al. 2009; Williams et al. 2008; Nasr & Ramadan 2008; Lim et al. 2009; Buzzetto-more & Alade 2006; Melero et al. 2012): comparable or improved learning performance as compared with part-task learning; deeper learning and improved higher-order thinking skills; superior far transfer of learning; increased intrinsic motivation; and superior interpersonal skills and student satisfaction as compared to traditional instruction. However, it must be recognised that PBL and pure discovery-based learning has been critiqued as negatively impacting cognitive load (Sweller & Cooper 1985; Moreno 2004; Moreno & Mayer 2007; Sweller 2004). Furthermore, PBL is still a significant shift in educational philosophy that to some extent remains out of step with current educational and assessment practices in high-schools. In accordance with (Lebow 1993; Jonassen 1999; Jonassen & Hung 2008; Buzzetto-More & Alade 2006; Williams et al. 2008; Nasr & Ramadan 2008; Liu et al. 2011; Melero et al. 2012), a number of challenges must be considered and overcome in PBL: significant pedagogical and instructional design experience is necessary to define and scaffold a problem that engages the learner's thinking processes without causing cognitive overload; the representation of the problem must be suitably rich in describing the necessary information, but not overly prescriptive; during PBL, new and unfamiliar roles and responsibilities are placed on both the teacher and the students; and in relation to the pedagogy defined in this study, the guided discovery inherent in this approach must carefully consider and balance with the structured e-learning environment.

4.7.1.4 Heuristic 4.1: Use Worked Examples to Support Problem-based Learning

The step-by-step demonstration of how to perform a task or solve a problem (worked example) is an approach advocated in cognitive load theory (Sweller & Cooper 1985; LeFevre & Dixon 1986; Chi et al. 1989; Chandler & Sweller 1991; Sweller et al. 1998; Moreno 2004; Sweller 2004; Schworm & Renkl 2007; Hattie 2009; Rourke & Sweller 2009; Anderman & Dawson 2011; Clark et al. 2006), although it is also considered in scaffolding and active learning principles within constructivism (Anthony 1996; Jonassen 1999). Worked examples are considered within the K12 Computer Science Framework (ACM et al. 2016). Additionally, Skudder and Luxton-Reilly (2014) report that the use of worked examples in computer science is widely used yet is a comparatively under-researched area. Meanwhile, Gray et al. (2007) offer some cautious success for the use of worked examples in teaching programming concepts, but not the holistic design process inherent in program-based solutions.

Findings from the following authors (Sweller & Cooper 1985; LeFevre & Dixon 1986; Chi et al. 1989; Schworm & Renkl 2007; Rourke & Sweller 2009; Anderman & Dawson 2011; Clark et al. 2006; Sweller 2004; Jonassen 1999) have informed the guidelines towards faded worked examples. In particular, the work of Clark and Mayer (2011) has significantly influenced the following characteristics of worked examples: gradually transition from worked examples to problems (as reflected in Figure 18); promote self-explanation of worked examples; where appropriate, selectively include instructional explanation of worked examples; and support far-transfer by using examples that provide the same underlying principles in different contexts.

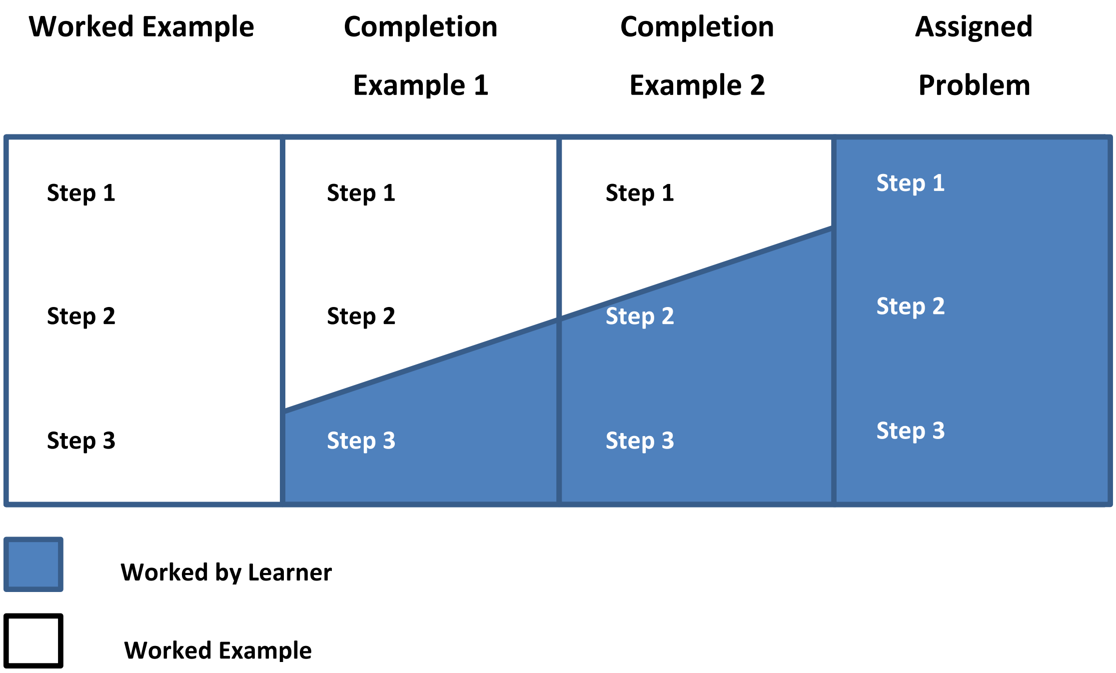


Figure 18: Gradual transition from worked examples to practice problems

Adapted from (Clark et al. 2011)

The aforementioned research claims the following potential benefits from the use of worked examples: reduction in cognitive load, increased learner preference towards worked examples over traditional instruction; improved learning performance, deeper learning; and when used in conjunction with multiple case studies, improved far transfer. However, after consideration of the expertise reversal effect[22], this pedagogy recommends faded worked examples (Sweller et al. 1998; Kalyuga & Ayres 2003; Sweller 2004).

4.7.1.5 Heuristic 5: Integrate Learning into Long-term Memory by using Authentic Examples, and Non-trivial Practice and Problems

To facilitate deep learning, students must integrate new learning material into existing schemas in their long-term memory. This allows learning to move beyond memorisation and fact recall, and enables the

[22] Worked examples become redundant, and can even hinder deep learning, when learners reach a sufficient level of experience.

more flexible application of knowledge and skills to scenarios not explicitly covered in the learning material.

This heuristic is informed by constructivism, social constructivism and cognitive load theory; it consolidates the heuristics outlined below to give focus to deep learning and far transfer.

- 1: Use authentic educational material, examples and activities.
- 2: Prompt reflective practice to support learning.
- 3: Make expert and learner thinking processes explicit.
- 4: Use problem-based learning (PBL) to facilitate learning.
- 4.1: Use worked examples to support problem-based learning.
- 6.2: Exemplify computational thinking in problem-solving activities.
- 9: Use social interaction to increase learning and promote higher-order thinking.
- 16.1: Support visual modal preference. Guideline 10, support for visualisation.

Refer to the aforementioned heuristics for further information.

4.7.1.6 Heuristic 7: Distribute Well-designed Practice Activities across the Lesson to Support Learning

A keystone principle within constructivism is that of active learning, whereby students actively engage their mental processes in practice exercises, reflective observation, theoretical conceptualisation and experimentation. This heuristic partially addresses the concept of active learning by the distribution of well-designed practice activities across the lesson to support learning. This encourages the mindful activity expounded by Jonassen (1999) and aligns with Hadjerrouit (2005), Buzzetto-more and Alade (2006), Hattie (2009), Moreno & Mayer (2007), Brooks and Brooks (1999), and Boud (2000) that instruction and learning is redesigned so that learning, practice and assessment are interwoven (and cannot be separated), with a focus on authentic and meaningful, learning and activities.

Findings from Clark and Mayer(2011), Sloboda et al. (1996), Tuffiash et al. (2007), Ericsson (2006), and Kellogg and Whiteford (2009), give clear evidence that practice activities that are deliberate, focused, persistent, and with appropriate feedback lead to increases in intrinsic motivation and learning performance. This leads to the following guiding characteristics for practice activities:

1. They should **integrate into the learning experience to support and solidify learning, instead of being used as a summative assessment**. This integration has further significance since these activities should be guided by the same heuristics intended for learning content (i.e. authentic and meaningful, preferably not shallow activities to recognise or reiterate facts);
2. As outlined by Clark and Mayer (2011) **the number and distribution of practice activities should be carefully considered in relation to intended learning objectives**, and whether there is a focus on improved learning performance, automaticity, exam preparation, long term retention or extended learning; and

3. As outlined by (J. M. Keller 1987a; Voelkel 2013; Brooks & Brooks 1999; Clark & Mayer 2011), **practice activities should provide variety and intrinsic motivation to maintain optimum engagement** (this relates to Heuristics 13 and 14).

As mentioned earlier, the benefits of giving a significant focus to practice activities is improved learner motivation and improved student performance. Furthermore, giving practice activities extended focus, improves efficiency and speed of execution (automaticity). However, it must be considered that practice can improve student performance almost indefinitely to an elite status, but with diminishing returns.

4.7.1.7 Heuristic 7.1: Provide Explanatory Feedback to Practice Activities to Promote Learning

A vital aspect in securing the benefits from practice activities is the provision of explanatory feedback, which in turn gives a further opportunity to promote learning. This is widely cited (Sadler 1989; Hattie 2009; Black & Wiliam 1998; Moreno & Mayer 2005; Moreno & Mayer 2007; Clark & Mayer 2011; Nicol & Macfarlane-Dick 2006) as a significant factor influencing learning achievement. Explanatory feedback as outlined in this pedagogy shares many of the underlying principles of formative assessment as discussed by (Voelkel 2013; Nicol & Macfarlane-Dick 2006; Taras 2005; Pachler et al. 2010). Additionally, when viewed through the lens of Sadler (1989), Black and Wiliam (1998), Boud (2000), and Nicol and Macfarlane-Dick (2006), there is additional alignment with constructivist principles in that the explanatory feedback should empower and support students as self-regulated learners, who have in mind the learning goals and, with some input, can self-regulate their performance towards those goals. Nicol and Macfarlane-Dick (2006), and numerous other authors, cite Sadler (1989) in outlining three knowledge areas essential for students to benefit from feedback:

1. Knowledge of what good performance is (i.e. what is the goal or standard being targeted);
2. Knowledge of how current performance compares to targeted performance;
3. Knowledge of how to bridge the gap between current and target performance.

Student knowledge of what the applicable learning goals and good performance are (Point 1), is discussed in heuristic 14.3 - guideline 1a. The above authors, and more specifically the following authors (Hattie 2009; J. M. Keller 1987a; Moreno & Mayer 2007; Black & Wiliam 1998; Clark & Mayer 2011), give basis to the following characteristics of explanatory feedback (that address Points 2 and 3):

1. **Provide feedback that tells the learner whether the answer is correct or incorrect, accompanied by a succinct explanation.**
2. **The explanation should provide cues, reinforcement or information on how to successfully complete a task or achieve learning goals.**
3. **Feedback should be provided at, or just above, the level where the student is learning.**
4. **Position the feedback in close proximity to both the question and answer, so the learner can see all together.**
5. **Feedback should focus on the task or task process and not on the learner.**

6. **Emphasise progress feedback that shows improvement over time.**
7. **In more complex problem-solving activities, that include multiple steps, it is important to provide step-wise feedback.**

Such feedback should then be used to complete the feedback loop (Sadler 1989) by giving students the opportunity to produce improved work in consideration of the received feedback.

As outlined previously, the positive influence of explanatory feedback (formative assessment) on learning performance is well cited, and is further evidenced by improved learning performance as compared to corrective feedback (Mayer et al. 2003; Moreno 2004; Moreno & Mayer 2005; Clark & Mayer 2011). Additionally, students express a preference towards explanatory feedback as being more helpful (Moreno 2004; Clark & Mayer 2011) and when applied successfully it can positively influence student engagement (Nicol & Macfarlane-Dick 2006).

4.7.1.8 Heuristic 13: Use Constructivist Approaches to Increase Intrinsic Motivation in the Learner

Intrinsic motivation stems from an interest or enjoyment in the learning or the activity itself, and originates within the individual rather than relying on external incentives. Motivation is important in giving the learner incentive to devote the mental energy to learn. A number of constructivist principles, such as whole-task and problem-based learning, authentic learning, active learning, mindful activity, etc., are shown to be intrinsically motivational and therefore supportive of the learning process.

This heuristic is primarily informed by constructivism and social constructivism learning theories; it consolidates the heuristics outlined below to give focus to intrinsic motivation.

- Focus on whole-task learning and problem-based learning (PBL): refer to heuristics 4, 6, and 6.2;
- Focus on authentic educational material, examples and activities: refer to heuristics 1, and 1.1;
- Focus on social and collaborative learning to improve student engagement: refer to heuristics 9, and 11;
- Enable learners to manage and take responsibility for their own learning: refer to heuristics 3, and 14.3;
- Convey the importance of the learning activity to the learner: refer to heuristic 1 and 14.2;
- Focus on active learning that encourages the student to actively engage their mental processes: refer to heuristics 2, 4, and 7; and
- Provide a problem manipulation environment that supports mindful activity: refer to heuristic 4 - guideline 9, and 6.2-guideline-4.

Refer to the aforementioned heuristics for further information.

4.7.2 Social Constructivism

Building on the review of social constructivism presented in section 2.4.4, this section further discusses social constructivist principles, and elaborates on how they are distilled into the e-learning heuristics outlined in Table 14.

ID	Heuristic
3	Make expert and learner thinking processes explicit.
8	Provide scaffolding to advance learning progress.
9	Use social-interaction to increase learning and promote higher-order thinking.
10	Engage learners in a challenge; target learning towards the zone of proximal development (ZPD).

Table 14: E-learning heuristics based on social constructivism

4.7.2.1 Heuristic 3: Make Expert and Learner Thinking Processes Explicit

According to Vygotsky (1978), humans' capacity for language is instrumental in their ability to overcome impulsive action, plan a solution to a problem prior to execution, and to master their own behaviour. Language is used for self-guidance, self-direction and external communication. However, despite these internal regulating and guiding capabilities, students often learn something without being clear on the rationale behind it, when to do it, how to gauge progress or whether the approach is working. The e-learning software and teachers (via the CLE) should make invisible mental processes explicit for the learner to understand and thereby implement. Likewise, learners must undertake activities to clarify and reflect on their underlying thinking and the rationale for their actions in resolving a problem (i.e. metacognitive thinking).

With a basis of the following research, (Vygotsky 1978; Schoenfeld 1987; Jonassen 1999; Boud 2000; Slack et al. 2003; Schraw et al. 2006; Barbour & Rich 2007; Anderson 2008; Fadel & Lemke 2008; Kop & Hill 2008; Chen et al. 2009; Illeris 2009; Denton 2012), the below guidelines were synthesised to make expert and learner thinking processes explicit:

1. **Make solution steps and underlying thinking explicit during problem-solving.** During problem-solving activities, the e-learning software and teachers (via the CLE) should model overt and covert performance by articulating the plan, implementing it and evaluating the cycle. Decisions, process steps and the underlying thinking and rationale for these decisions or steps should be made explicit via a running commentary, and / or visualisation (with accompanying signposting).
2. **Focus attention on expert behaviour.** In line with kinaesthetic learning, expert behaviour should be demonstrated, and the desired behaviour signposted to focus learner attention.
3. **Promote learner reflection on their own thinking processes.** Focus should be expanded beyond finding the final solution to also include opportunities for learners to comment on their progress and articulate their thinking in working on a problem. To promote further self-reflection, teachers can provide feedback or students can enter a pair or group reflection in which they can discuss, justify and comment on theirs and others' thinking processes.

Expert thinking can be made explicit by the provision of a running commentary of the underlying thinking and rationale for decisions, this commentary can be implemented in audio, video, animation or text in the e-learning software. The CLE can be used by the teacher to demonstrate expert behaviour and thinking. Additionally, the learners can undertake activities on the CLE to reflect on their own thinking processes.

By explicitly exposing thinking processes in varying contexts, the learner is able to model them, incorporate them in their own thinking, and reflect on their own thinking processes. This in turn leads to a comparative improvement in: immediate learning performance, deep learning, far transfer, and more robust problem-solving skills. However, it must be considered that making invisible thinking processes explicit is a challenging task that requires a high level of metacognitive skills in the teacher, or instructional designer designing the e-learning software. In addition, it also creates a secondary layer of metacognitive learning that, if not considered with measure, may overload or distract students from the primary topic.

4.7.2.2 Heuristic 8: Provide Scaffolding to Advance Learning Progress

Scaffolding is the process by which a teacher or other guiding figure (including the e-learning software or more knowledgeable students) provide additional instructional assistance, coaching, guidance, or prompting that supports a student's learning process so they can accomplish learning or problem-solving that is normally beyond their unassisted efforts.

The research of (Sweller & Cooper 1985; Jonassen 1999; Vrasidas 2000; Karagiorgi & Symeou 2005; Buzzetto-More & Alade 2006; Schraw et al. 2006; Kop & Hill 2008; Lee et al. 2008; Chen et al. 2009; Pritchard 2009; Caballé et al. 2010; Vogel-Walcutt et al. 2011; Melero et al. 2012) was considered in this heuristic and the synthesis of the following guidelines to support scaffolding:

1. **Choose appropriate scaffolding or combination of scaffolding approaches for the situation:**
    a. **Macro-scaffolding** – Provides high-level guidance on how to approach a learning task or problem activity. It can give a general workflow to be followed in order to accomplish the desired learning outcomes.
    b. **Micro-scaffolding** - Provides scaffolds for solving detailed actions that focus on specific learning activities.
    c. **Automated Scaffolding** – Automated scaffolding is macro or micro-scaffolding that is incorporated in the instructional design and is delivered by the e-learning software.
    d. **Social-scaffolding** – Macro or micro-scaffolding provided by some form of social interaction with a teacher or other guiding figure.
2. **Choose a variety of scaffolding techniques, including:**
    a. Use explanatory feedback to support student learning (Heuristic 7.1).
    b. Use screencasts that focus on detailed actions on specific learning activities.
    c. Use simulations, animations and other visualisation tools to help learners construct their mental images and visualise activities (Heuristic 16.1 guideline 10).
    d. Pre-plan for students to request scaffolding on some low-level tasks by including a "Hint" button that can be used when needed.

e. Provide worked examples that gradually transition to full problems (Heuristic 4.1).
f. Present related case studies - providing case studies with different contexts but the same underlying principles supply the learner with a rich set of experiences to guide them in resolving the current problem.
g. Articulate Reasoning – An expert model's problem-solving or other skills which is used to articulate the implicit reasoning and decision-making involved in each step of a process (Heuristic 3).
h. Behavioural Modelling – Expert behaviour is modelled by demonstrating how to perform certain activities and signal important steps (Heuristic 3).

3. **Gradually remove scaffolding support as learners advance and develop their own learning strategies.**

The correct use of scaffolding can provide the following educational benefits: support learners in reaching their full potential (i.e. their ZPD) and the expected learning outcomes; reduce cognitive load during constructivist and whole-part instruction, thereby mitigating the potential for cognitive overload in these approaches; and improve student engagement and satisfaction. However, scaffolding support should be gradually removed as learners advance and develop their own learning strategies, otherwise it may frustrate advanced learners or impede the progress of learners to more advanced levels.

4.7.2.3 Heuristic 9: Use Social-Interaction to Increase Learning and Promote Higher-Order Thinking

As outlined briefly in section 2.4.4, according to Vygotsky (1978, p.57), "*Every function in the child's cultural development appears twice: first, on the social level, and later, on the individual level; first, between people (inter-psychological), and then inside the child (intra-psychological)*." Whilst this assertion is disputed by some, social constructivism is well recognised since it builds upon cooperative and collaborative learning and reflective learning practices to emphasise the importance of social interactions in shaping the learner's knowledge construction. It supports learners in reaching a higher level of learning than can be achieved individually. In addition, the social interaction of individuals can often lead to learning that is greater than the sum of the individuals, and can ultimately result in a shared understanding inherently derived from the learning community.

The research of (Vygotsky 1978; Dillenbourg et al. 1995; Jonassen 1999; Squires & Preece 1999; Boud 2000; Vrasidas 2000; Karagiorgi & Symeou 2005; Schraw et al. 2006; Barbour & Rich 2007; Kop & Hill 2008; McLoughlin & Lee 2008; Anderson 2008; Pritchard 2009; Shroff & Vogel 2009; Bell 2011; Caballé et al. 2010; Chai & Lim 2011; Chiong & Jovanovic 2012; Clark & Mayer 2011; Melero et al. 2012) is considered in this heuristic, and underpins the synthesis of the following guidelines to support social learning:

1. **Use social interaction to foster learners' ability to develop an opinion and evaluate their opinion in relation to other peoples' opinions.** The e-learning software and collaborative learning activities (supported by teachers) should give an increased focus on social (collaborative or cooperative) activities that foster students' ability to develop an opinion,

evaluate their own and other peoples' opinions, justify their thinking, and openly discuss their interpretation.

2. **Provide a suitable learning environment and context for social interaction.** The activities in point 1 always involve an open dialogue, typically within a community of learners. The instructional design of the e-learning software and collaborative activities should provide an authentic context, typically within a problem-based learning (PBL) approach in which learners cooperate and learn together to solve a non-trivial authentic problem.
3. **Provide expert knowledge, behaviour and guidance.** Social interaction is not restricted to only other learners; it is also facilitated by a more knowledgeable other. This can often take the form of a cognitive apprenticeship where teachers (the experts) work alongside students (the apprentices) within a situated context. The e-learning software and/or the teacher (via the CLE) act as the expert to demonstrate appropriate behaviour, and offer scaffolding to support the apprentices in working on a problem or activity.

Social constructivist learning interactions can potentially offer the following educational benefits:

1. The primary benefit is to promote higher-order thinking by encouraging learners to develop, evaluate, and appreciate multiple perspectives on an issue, this can ultimately lead to a shared consensual meaning, or if not, at least individual learning that is informed by other perspectives.
2. The underlying principles and collaborative nature of social constructivism also lead to greater student engagement and learning that is more meaningful.
3. Although not explicit in the instructional objectives, social constructivism also allows the sharing of learner workload through cooperative learning, and the building of consensus through collaboration.
4. Social scaffolding approaches can help reduce cognitive load, thereby mitigating the potential for cognitive overload.

However, it is important to note that there remains a significant need for individual learning; not all learning should be made social, and not all learning material is suitable for social learning. Additionally, there is significant effort involved in devising successful collaborative work, forming effective groups, and maintaining productive social dialogue and learning. Also, some learners, such as those with a dominant read-write modal preference (Heuristic 16.3), are not as responsive to social learning as others. Furthermore, although recent literature suggests the trend is changing, it should also be noted that, to some extent, social learning remains out of step with current educational and assessment practices in schools.

4.7.2.4 Heuristic 10: Engage Learners in a Challenge; Target Learning Towards the Zone of Proximal Development (ZPD)

Vygotsky postulates that a true measure of a student's capabilities is not addressed by focusing on their actual developmental level, but that "*what children can do with the assistance of others might be in some* *sense even more indicative of their mental development than what they can do alone*" (1978, p.85). This theory is elaborated in the Zone of Proximal Development (ZPD). The ZPD is a theoretical space of understanding which is just above the level of understanding of a given individual, and which can only be reached with support. It is the necessity of this support by others that explains the importance of social interaction for learning development. It should be noted that the role of the more knowledgeable other is not a role reserved only for the teacher; it is often taken by a more capable peer.

The research of (Vygotsky 1978; Vrasidas 2000; Karagiorgi & Symeou 2005; Barbour & Rich 2007; Pritchard 2009; Melero et al. 2012) is considered in this heuristic and the synthesis of the following guidelines to support the Zone of Proximal Development:

1. **Educational material should progressively increase in challenge and maintain the learner at the upper limits of their current learning capacity.** The level of educational material and activities should progressively increase in difficulty as the learner progresses, thus encouraging the students to work at the upper limits of their current learning capacity.
2. **Teachers should be able to easily update text and visual learning material to be more challenging.** The e-learning software should provide the technical affordance for teachers and instructional designers to easily update text and visual learning material to be more challenging to their student audience.
3. **Learners should be supported with scaffolding and access to more knowledgeable others.** In order to avoid feelings of disappointment, learners must have comprehensive scaffolding support (Heuristic 8) and access to more knowledgeable others who can give assistance in reaching the next learning level, or when the learning process is blocked.
4. **Learners should have access to a learning community.** A collaborative learning environment (CLE) should be provided to support the community of learning and facilitate social interactions between learners and more knowledgeable others. Within the community of learning, there will be multiple overlapping ZPDs and the social interaction between students of different ZPD levels will drive an overall improvement in levels of understanding.
5. **Provide learning content and activities that adapt to the learner's current abilities and progress.** Adaptive e-learning software can automatically adjust to the learner's current knowledge and skill level and progress to material, activities and questions that are more challenging, or alternatively revisit previous material if the learner has not adequately mastered it.

The purported educational benefit of the ZPD is that it motivates learning that stretches the learner's existing capabilities, and encourages them to the next higher level of learning. Vygotsky theorised that child development (physical and mental maturation) are **not** independent of learning, and that by focusing on the ZPD, the child's mental development is encouraged.

In an idealised situation, the teacher or more knowledgeable other must recognise the individual learner's current state of understanding and plan accordingly to stimulate and support learning at the next higher level. This is a very difficult task for teachers and instructional designers to achieve with a class of students.

This poses the risk when setting progressively more challenging learning material that some learners may be left behind or become disappointed. This should be mitigated by the use of scaffolding and individualised support via the collaborative learning environment.

Another approach is to implement adaptive learning into the e-learning software; however, this too must be considered in relation to the significant additional effort in creating supplementary educational content, multiple adaptive learning pathways, and the complexities and additional development of the software.

4.7.3 Collaborative Learning

Building on the review of collaborative learning presented in section 2.4.5, this section further discusses collaborative learning principles and elaborates on how they are distilled into the e-learning heuristics outlined in Table 15.

ID	Heuristic
11	Use collaborative learning activities.
11.1	Support collaborative and situated learning via mobile devices.

Table 15: E-learning heuristics based on collaborative learning

4.7.3.1 Heuristic 11: Use Collaborative Learning Activities

Knowledge construction and integration in schemas (in long-term memory) happens on an individual level; however, it is evident that other people affect the learning process, and that arguably learning most naturally occurs not in isolation, but when students work together. Collaborative learning capitalises on other people's knowledge, skills and resources, allowing learners to monitor one another's work, share information, summarise points, verify and test their knowledge, and debate their opinions.

With a basis of the following research (Roger & Johnson 1988; Johnson & Johnson 1996; Jonassen 1999; Lou et al. 2001; Mayes & de Freitas 2004; Mitchell & Savill-Smith 2004; Alonso et al. 2005; Dabbagh 2005; Karagiorgi & Symeou 2005; Nuutila et al. 2005; Palmer 2005; Gilbert et al. 2007; Anderson 2008; Beck & Chizhik 2008; Tutty & Klein 2008; Black & Wiliam 2009; Kirschner et al. 2009; Nicholas & Wan 2009; Papanikolaou & Boubouka 2010; Clark & Mayer 2011; Slavin 2011; Chiong & Jovanovic 2012; Denton 2012; Ryoo et al. 2013; Waite 2017) this heuristic, and the following guidelines, were synthesised to maximise the benefits of collaborative learning. The instructional design of the e-learning software and collaborative activities should incorporate a subset of the following guidelines:

1. **Ensure Social Interdependence of the group.** In collaborative learning, incentives (feedback and/or grading) should be based on a synthesis of individual and group outcomes, aligned to ensure that each team member participates and supports the learning of the rest of the team.
2. **Design the collaborative activity based on intended learning outcomes.** The desired outcome of the collaboration must be considered from the outset, and the activity designed accordingly. The outcome of collaborative learning typically falls into two main areas; either improved

individual learning or an increase in the quality of the project deliverable(s). However, since individual achievement does not necessarily correlate with group achievement or the quality of group deliverables, it is critical to decide from the outset what the expected outcome from the collaboration is.

3. **Design the collaborative activity to ensure the quality of the collaborative dialogue.** The design of collaborative activities must ensure substantive contributions by all team members. Poor instructional design can lead learners to shallow or non-participation in collaborative activities. Adapt instructional material to promote interdependence. Avoid difficult activities that have incentives that encourage one or two individuals to take on most of the work, or activities that are too easy, unstructured or not designed to promote discussion or true collaboration. Example activity types include: collaborative problem-solving; cooperative problem-solving; peer instruction, scaffolding and feedback; brainstorming, discussion and debate; collaborative reflection; collaborative editing; and pair programming.
4. **Provide structure and support for collaborative activities**
   a. Clearly communicate objectives and deliverables for the collaborative activity.
   b. Provide relevant instructions, guidance, problem description and context information for the collaboration; at least enough information to start further enquiry.
   c. Consider assigning roles to the group members to provide structure to the process (e.g. solution creator, reviewer, moderator, etc.). The roles can then be switched to ensure equal coverage.
   d. Consider providing macro-scaffolding for the collaborative process. This can take the form of high-level guidance on how to approach the collaborative activity, and can give a general workflow to be followed in order to accomplish the desired learning outcomes.
   e. If necessary, teachers may need to intercede and act as a facilitator for the collaboration.
5. **Consider team size and composition.** Team composition should typically either be heterogeneous teams consisting of high and low prior knowledge learners, or homogeneous teams consisting of high or medium prior knowledge learners. Avoid homogeneous teams consisting of low prior knowledge learners. Factors to consider include:
   a. The inherent complexity of the learning activity or task.
   b. The learning material or nature of the task, which may impose on the group size.
   c. With increased group size comes a theoretical increase in the range of abilities, expertise, skills, and cognitive capacity.
   d. With increased group size comes an increased overhead in effectively managing and coordinating the group.
   e. The shorter the period of the collaborative activity, the smaller the group should be.
   f. If individual learning is the outcome goal, then consider pair work.

g. If creative problem-solving is the outcome goal, then consider a larger group of three to five team members.

6. **Prepare students for collaborative activities.** Ensure the team have sufficient social skills to manage conflict and that interactions are directed towards rational debate. This can be accomplished by pre-training or by setting appropriate guidelines.
7. **Monitoring and Intervening.** The e-learning software and CLE must offer the technical affordance for teachers to observe group performance in collaborative activities and their subsequent deliverables, and the ability to provide support to the group in the task or in the collaborative process.

To support collaborative and social learning, the e-learning software should be supplemented by a collaborative learning environment (CLE). Students using the e-learning software should also be registered on the CLE and the e-learning software will then direct learners to the CLE to undertake collaborative activities. A synthesis of the following research (Jonassen 1999; Buzzetto-More & Alade 2006; Gilbert et al. 2007; Anderson 2008; Siemens 2008; Couros 2009; Nicholas & Wan 2009; Halse et al. 2009; Boyle et al. 2010; Caballé et al. 2010; Clark & Mayer 2011; Denton 2012; Jenkins et al. 2012) recommends that the CLE should implement a number of the following collaborative technologies (refer to Table 16):

Blog and Micro-blogs	**Voice Over Internet Protocol** (VOIP)	**e-Portfolios**
Video Conferencing	**E-Mail**	**Social Networks**
Text Chats (Internet Relay Chat)	**Discussion (Message) Boards**	**Wikis**
Online Conferencing (Virtual Classrooms / Breakout Rooms)	**Cloud Office Applications**	**Cloud Integrated Development Environments**
Virtual Environments		

Table 16: Collaborative technologies to be supported in a collaborative learning environment.

In line with the following research (Roger & Johnson 1988; Lebow 1993; Johnson & Johnson 1996; Vrasidas 2000; Barbour & Rich 2007; Tseng & Tsai 2007; Beck & Chizhik 2008; Sun et al. 2008; Tutty & Klein 2008; Barker et al. 2009; Cole 2009; Halse et al. 2009; Kirschner et al. 2009; Papanikolaou & Boubouka 2010; Kang et al. 2010; Slavin 2011; Zenios 2011; Chiong & Jovanovic 2012), the benefits of collaborative learning include:

1. Under certain conditions, collaboration can substantially improve student achievement.
2. It can improve long-term retention and support higher-order thinking, meta-cognition and problem-solving by encouraging learners to develop, evaluate, and appreciate multiple perspectives on an issue.
3. It can lead to greater student engagement and learning that is more meaningful.
4. It allows the sharing of learner workload through cooperative learning and building consensus through collaboration.

5. Cooperativeness is positively related to indices of psychological health such as: "*emotional maturity, well-adjusted social relations, strong personal identity, and basic trust in people*" (Johnson et al. 1984, p.22).

However, it should be noted that collaborative learning attempts to instigate certain forms and types of interactions that encourage learning, but there is no guarantee that improved learning or any of the other benefits of collaborative learning will occur. Johnson & Johnson maintain that "*Many groups are ineffective, and some are even destructive. Almost everyone has been part of a group that has wasted time and produced poor work*" (1996, p.793), and that such groups are typically categorised by a number of dynamics such as "*social loafing, free riding, group immaturity, uncritical and quick acceptance of members' dominant response, and group-think*" (1996, p.793). Other authors, such as (Tutty & Klein 2008; Williams et al. 2008; Kirschner et al. 2009; Nicholas & Wan 2009; Papanikolaou & Boubouka 2010; Lee & Choi 2011; Zenios 2011; Chiong & Jovanovic 2012), have also noted sub-optimal conditions for collaborative learning. This means that the teacher effort in implementing guidelines one to seven are significant, as are the efforts of the students working collaboratively.

Furthermore, as outlined in heuristic 9, there remains a significant need for individual learning, not all learning should be made collaborative and not all learning material is suitable for collaborative learning. Additionally, some learners, such as those with a dominant read-write modal preference (Heuristic 16.3), are not as responsive to collaborative learning as others.

An important factor is that technology-enhanced collaborative learning can offer limited value in a classroom context; depending on the learning context and technology used, often students can more naturally collaborate in person.

As previously commented, it should be remembered that to some extent, collaborative learning remains out of step with current educational and assessment practices in schools.

4.7.3.2 Heuristic 11.1: Support Collaborative and Situated Learning via Mobile Devices

Arguably, we are currently living through a paradigm shift from education in formal settings towards education that extends beyond the classroom to become more situated, personal, collaborative and informal. This paradigm shift is supported by the explosion of mobile devices, their significantly enhanced capabilities, pervasive wireless networks and cloud computing that enable communication, collaboration and sharing of information resources almost anywhere.

This heuristic and its guidelines build upon and extend the research in heuristic 11, by focusing on mobile learning (m-learning) research (Mayes & de Freitas 2004; Anderson 2008; Shen et al. 2009; Caballé et al. 2010; Chai & Lim 2011). To support m-learning the following guidelines should be considered:

1. **The instructional design of the e-learning software and collaborative learning activities should support asynchronous usage** (self-directed learning).

2. **The implementation of the e-learning software should be developed considering technologies that are commonly accessible on mobile devices** (e.g. web browsers, HTML5, audio and video playback and recording, etc.).
3. **The instructional design and implementation of the e-learning software should support "responsive design"**, enabling intrinsic support for the form factor and characteristics of mobile devices.
4. **The instructional design and implementation of the e-learning software should be enhanced to take advantage of learning opportunities only available on mobile devices** (e.g. location awareness, device to device communication, gyroscopic control, etc.).

There are three main benefits of supporting mobile devices for e-learning:

1. Today's mobile devices are ubiquitous; enhancing the e-learning software for use with mobile devices immediately increases the access points available for the software.
2. By design, mobile devices excel at multimedia presentation, communication and collaboration.
3. Learning can happen anywhere and at any time; the inherent mobility of mobile devices means student learning is no longer confined to the classroom and can become more situated; it can happen almost anywhere either formally or in an informal context.

Although there is a general increase in the size of mobile phones and a trend towards larger size phablets, there remains a concern that the relatively restricted form factor of mobile phones and tablets may pose some restrictions on the educational content and inhibit true active engagement, thereby increasing the risk that m-learning may lead to more passive information consumption.

As noted in the parent heuristic, an important factor is that technology-enhanced collaborative learning offers limited value in a classroom context in which students can much more naturally collaborate in person. However, there are some specific classroom uses that can add educational value, such as anonymous student questions or instant polling functions that allow immediate feedback on the lesson.

It should also be noted that to some extent, m-learning is out of step with current educational and classroom practices in high schools, and as such may not be an immediate priority to be supported by e-learning software.

4.7.4 Connectivism

Building on the review of connectivism presented in section 2.4.6, this section further discusses connectivist principles and elaborates on how they are distilled into the e-learning heuristics outlined in Table 17.

ID	Heuristic Title
1.1	Ensure the currency of learning material.
12	Develop and nurture networks to support learning.

Table 17: E-learning heuristics based on connectivist principles

4.7.4.1 Heuristic 1.1: Ensure the Currency of Learning Material

The currency of information and learning material is strongly related to the constructivist principle of authenticity; hence, it is positioned as a sub-heuristic. The nature of information is that it is constantly changing; therefore, the overriding aim is that by focusing on the currency of learning material (nodes), accuracy and validity must be re-evaluated, which in turn leads to a re-evaluation of existing knowledge and the possibility to learn more.

The process by which students refresh their knowledge is a learning process that cannot be automated, but can be supported by the e-learning software and collaborative learning environment employing the following criteria: learning material and activities are up-to-date and easily editable so they can be kept current; the e-learning software should act as a focal point that recommends other learning resources (nodes on the learning network) that are current; technology[23] is used to keep up-to-date; and other people can provide up-to-date information via the CLE.

The criteria in this heuristic provide support for Connectivist principles 1, 2, 3, 6 and 7 (refer to section 2.4.6). However, it should be noted that they do so by following a moderate connectivist approach; as discussed by Siemens (2008) citing Bonk (2007), teachers, and in this case the e-learning software, can act as a *'concierge directing learners to resources or learning opportunities'*. Again, in alignment with Siemens (2008), connectivist principles 4, 5 and 7 are supported by the pedagogy by the acknowledgement and recommendation that this heuristic requires critical and metacognitive skills that students may not inherently have; therefore, additional support and instruction from teachers will be required. The changing role of teachers and the significant need for learner critical and metacognitive thinking is well documented within connectivism (Siemens 2004; Siemens 2008; Couros 2009; Downes 2006; Boud 2000; McLoughlin & Lee 2008; Kop & Hill 2008) and other writings (Jonassen 1999).

It is theorised by connectivists that following these underlying principles leads to learning that is aligned with our current digital society and the NET generation. More specifically, that learning is no longer constrained by one book or one perspective that may become outdated; instead, through connectivism, the learner has access to a variety of existing nodes that are kept up-to-date or replaced by new nodes and new contributors. This gives the learner the opportunity to experience learning that is refreshed and kept up to date. To some extent, this heuristic is out of step with current educational practice in which there is a single set syllabus and set texts that are to be examined. It is clear that in the current educational climate this cannot be abandoned; nonetheless, there remains room for students to search and explore new information that may be more current.

[23] Push and pull technologies can help support the process of refreshing one's knowledge by delivering changing learning material. One such technology is Rich Site Summary (RSS) web feeds, which deliver regularly changing web content to whoever wants to subscribe.

4.7.4.2 Heuristic 12: Develop and Nurture Networks to Support Learning

Connectivists propose that knowledge lies in a diversity of opinions, and that this knowledge resides in a network of interconnected entities called nodes. These nodes can be almost anything with learning value, such as individuals, groups, systems, fields, ideas, or communities, but for the most part the focus lies on humans and digital resources. Considering the eight underlying principles of connectivism and the more moderate connectivist approach already discussed, we arrive at the following heuristic criteria: the e-learning software should act as a focal point that recommends other learning resources (nodes on the network) through web links; the e-learning software should promote collaborative learning interactions with other students and/or teachers; the learning process should be cyclical in nature[24]; the e-learning software and its constituent learning objects should act as nodes on the network[25]; the e-learning software can make use of information and other learning resources found on the network[26]; and the learning network, where possible, can be developed into a learning community.

With reference to the creation of a learning community, it should be noted that the e-learning software should promote collaborative learning interactions (group assignments, collaborative blogging, peer reviews, etc.) in the CLE, thereby introducing the students to the learning community. However, forming and maintaining a learning community places significant extra requirements on both teachers and those acting as facilitators, as well as the learners. With this in mind, the work of Rovai (2002), Brown (2001), and Blas & Poggi (2007) have been synthesised into a set of guidelines for community building, which is included in the appendices of the e-learning pedagogy. It should also be noted, as discussed in the previous connectivist heuristic, the need for critical and metacognitive skills is also required in this heuristic.

The key benefits of connectivism and the use of learning networks is that students are less constrained by didactic teaching approaches; instead, they have increased freedom to explore and assimilate learning from a variety of other resources, such as other people, web pages, blogs, educational videos, animations, simulations, etc. The exploration of other nodes and networks containing potentially different perspectives and information allow the students to build their knowledge actively. Furthermore, if there is a focus on collaborative learning, or the learning network is developed into a learning community, then there is potential for increased learning performance, improved higher order thinking, and increased learner motivation and satisfaction.

It should be noted that connectivist principles are not appropriate for all learners and should be considered with care to not negatively impact cognitive load and the structured environment of the e-learning software.

[24] The learner joins the network to gather information, will make sense of the information they find, update their understanding, and will later reconnect to the network to share these realizations and new understanding.

[25] The e-learning software should be composed of SCORM (Shareable Content Object Reference Model) Learning Objects, which in themselves can be individual learning nodes on the network for students to learn from.

[26] This should be within the limitations of copyright law and acknowledge the original authors.

4.7.5 VARK Learning Styles

Building on the review of VARK learning styles presented in section 2.4.7, this section further discusses VARK principles and elaborates on how they are distilled into the e-learning heuristics outlined in Table 18.

ID	Heuristic
16	Use multi-modal learning approaches.
16.1	Support visual modal preference.
16.2	Support aural modal preference.
16.3	Support read-write modal preference.
16.4	Support kinaesthetic modal preference.

Table 18: E-learning heuristics based on VARK learning styles

4.7.5.1 Heuristic 16: Use Multi-modal Learning Approaches

Students are not restricted to only one of the modal preferences (visual, aural, read-write, or kinaesthetic). It is typical for students to exhibit a preference for one particular mode, and a relative weakness or strength in some other modes. However, it must be recognised that even the relatively weaker modes cannot be ignored; even if a student has a strong preference on a certain modality, they should still be exposed to diverse learning experiences, and encouraged to develop into more versatile learners. The e-learning software should accommodate the four modalities by providing a variety of different learning options that consider the different learning styles. By combining a mixture of approaches, the students are given the possibility to choose the instructional style that best fits their own individual learning style(s).

The theoretical foundations and guidelines for this multi-modal learning heuristic are detailed in research by (Dunn et al. 1981; Felder & Silverman 1988; Fleming & Mills 1992; Fleming 1995; Johnson & Johnson 1996; Jonassen 1999; Jones et al. 2003; Frank Coffield et al. 2004; Mitchell & Savill-Smith 2004; Fleming & Baume 2006; Zapalska & Brozik 2006; Anderson 2008; Fadel & Lemke 2008; Gardner 2009; Pritchard 2009; Leite et al. 2010; Othman & Amiruddin 2010; Popescu 2010; Birch et al. 2011; Clark & Mayer 2011; Fleming 2012). Distilling research in this area recommends that the e-learning software and collaborative activities should consider a significant subset of the following guidelines:

1. **The e-learning software and associated CLE activities incorporate learning material that supports the four VARK modal preferences.** The approaches and activities appropriate for each modal preference are outlined in the following heuristics.
    - 16.1: Support visual modal preference.
    - 16.2: Support aural modal preference.
    - 16.3: Support read-write modal preference.
    - 16.4: Support kinaesthetic modal preference.

2. **The e-learning software and associated CLE activities should provide an approximate balance between the four modal preferences.**
3. **The choice and balance of modal channels must carefully consider and align with the learning context and content.** Not all modal channels are appropriate or optimal for conveying specific learning material.
4. **The e-learning software and associated CLE activities should support the four modal preferences without causing cognitive overload to the students.**

As discussed in section 2.4.7, the successful implementation of VARK learning styles and multi-modal learning requires the VARK inventory to be used as a catalyst for reflection, self-awareness and dialogue. It is therefore important to ensure the students have the metacognitive skills and strategies to effectively utilise the multi-modal material.

Considering the previously mentioned authors, and specifically work from (Weiler 2005; Zapalska & Brozik 2006; Moreno & Mayer 2007; Fadel & Lemke 2008; Pritchard 2009; Othman & Amiruddin 2010; Popescu 2010; Birch et al. 2011; Katsioloudis & Fantz 2012), the use of multi-modal learning can potentially result in the following educational benefits:

1. Knowledge of learning styles and adjusting instructional approaches and resources to complement them is shown to increase learning performance.
2. The communication of learning material via multiple modalities provides increased support for learners to understand and assimilate the learning into existing schemas in long-term memory (deep learning).
3. Giving focus, or at least options, for students to learn via their preferred perceptual mode increases their motivation.
4. Exposing students to learning material across the modalities and encouraging their learning development can enable students to become more versatile learners.
5. The underlying nature of certain concepts, and even certain subjects, makes different modalities more appropriate in their teaching.

It is important to note that multi-modal approaches must be mitigated by a consideration of cognitive overload and the work of (Mayer et al. 2001; Moreno & Mayer 2002; Mayer et al. 2003; Mayer & Moreno 2003; Moreno & Mayer 2007; Fadel & Lemke 2008; Anderson 2008; Alonso et al. 2009; Birch et al. 2011) on dual encoding; students do not have infinite working memory or cognitive capacity. It is important to not overload the students with too many competing channels of learning communication. The instructional design of the e-learning software must ensure that students do not feel pressured into trying to take in information from all the modal channels, or worse, to take them in and try to compare them.

Additionally, from a more practical perspective, designing and producing multiple versions of pedagogically appropriate learning material designed to work in concert is a skilled, time consuming, and potentially expensive approach.

4.7.5.2 Heuristic 16.1: Support Visual Modal Preference

Visual learners prefer graphical and symbolic ways of representing information. They have good visual recall and prefer information to be presented visually, in the form of diagrams, graphs, maps, posters, displays, etc. In addition, where learning material is complex, includes invisible or difficult to see phenomena, or has difficult concepts or process steps, then special attention must be given to visualisation tools that help learners to construct appropriate mental images and visualise activities.

As a sub-heuristic of heuristic 16, this heuristic builds upon the research outlined in its parent, but gives more specific focus to visual approaches and guidelines as detailed in research by (Fleming & Mills 1992; Fleming 1995; Jonassen 1999; Jones et al. 2003; Hegarty 2004; Betrancourt 2005; Condie & Munro 2007; McCartney et al. 2007; Nasr & Ramadan 2008; Jarmon et al. 2009; Pritchard 2009; Othman & Amiruddin 2010; Allen et al. 2011; Clark et al. 2006). Distilling research in this area recommends that the e-learning software and collaborative activities should support visual learning via an appropriate subset of the following.

1. **Learning material that is rich in visual depictions such as:**

Diagrams	Maps	Mind-maps
Posters	Graphs	Displays
Flowcharts	Multimedia	Symbolic representations
Graphical organisers	Visual demonstrations	Visual modelling

2. **Represent thought processes as visual representations.**
3. **Focus on the big picture with holistic instead of reductionist approaches.**
4. **Use underlining, highlighters and different colours.**
5. **Link text with associated diagrams and pictures.**
6. **Use non-visual learning that is appealing to visual learners:**
    a. Provide past examples of finished products
    b. Activities that allow freedom and emphasise creativity
    c. Group learning
    d. Roleplay
7. **Avoid over focus on word usage, syntax and grammar.**
8. **Promote activities to convert notes into one-page pictures, and vice versa.**
9. **Provide the opportunity for students to use diagrams and visual elements in answering questions and in assignments.**
10. **Support visualisation by including visual representations of learning material that is very complex, includes invisible or difficult to see phenomena, or has difficult concepts or process steps.** The e-learning software should include the appropriate use of task or domain-specific images, animations, simulations, static frames and video to enable students to visualise learning material.

This heuristic builds upon the educational benefits discussed in heuristic 16. However, in addition, with regard to guideline-10, embodying learning material according to visualisation approaches optimises essential processing by reducing the complexity of the learning material and presenting it in a way that is easier for the learner to assimilate. Furthermore, it helps in building accurate mental schemas that can be integrated with existing knowledge, thereby maximising germane cognitive processing.

4.7.5.3 Heuristic 16.2: Support Aural Modal Preference

Auditory learners prefer to learn from listening. They have good auditory memory and benefit from lectures, tutorials, discussions with other students and teachers, interviewing, hearing stories, audio tapes, etc.

As a sub-heuristic of heuristic 16, this heuristic builds upon the research outlined in its parent, but gives more specific focus to aural approaches and guidelines, as detailed in research by (Fleming & Mills 1992; Fleming 1995; Pritchard 2009; Othman & Amiruddin 2010; Allen et al. 2011; Birch et al. 2011). Distilling research in this area recommends that the e-learning software and collaborative activities should support aural learning via an appropriate subset of the following:

1. **Give additional focus to auditory learning material.**
2. **Promote lectures and tutorials that are primarily focused around hearing the teacher talk.**
3. **Emphasise oral presentation, instructions, questioning, answers and reward.**
4. **Promote discussion activities with other students and/or teacher.**
5. **Promote activities to orally describe overheads, pictures and other visuals to somebody else.**
6. **Promote activities to record interesting examples, stories and jokes as memory aids.**
7. **Promote activities to create audio versions of instructional texts and learner notes.**
8. **Promote activities to interview experts.**
9. **Promote activities to read written notes aloud.**
10. **Promote activities to supplement existing written notes by talking with others and collecting notes from the textbook or other learning resources.**
11. **Promote activities to orally report your understanding of a topic or explain your notes to another aural person.**

Audio recording and playback has become quite an easy activity using an audio player/recorder or via the vast majority of mobile phones and computers. Likewise, there is a large number of audio/video streaming and chat software that can be used for lectures, tutorials and discussions. The aural approaches outlined can be used in face-to-face activities, or implemented in the e-learning software or through pedagogically appropriate activities in the CLE. However, it is important that the e-learning software gives support to either enable / disable audio, and remains pedagogically effective even when audio is disabled.

Although, the recording of audio has become a relatively simple activity, it still may require additional support from teachers to educate students and potentially to give the student access to audio recording equipment. Furthermore, audio recording and playback activities are complicated by a shared classroom environment and noise overlap between students. This can be partially mitigated by headphones, but this in turn becomes an additional hardware resource necessary to support the e-learning software.

4.7.5.4 Heuristic 16.3: Support Read-write Modal Preference

Read-write learners prefer to learn through information displayed as a word; they benefit from lecture notes, note-taking, journals, lists, definitions, textbooks, etc.

As a sub-heuristic of heuristic 16, this heuristic builds upon the research outlined in its parent, but gives more specific focus to read-write approaches and guidelines, as detailed in research by (Fleming & Mills 1992; Fleming 1995; Pritchard 2009; Othman & Amiruddin 2010; Allen et al. 2011). Distilling research in this area recommends that the e-learning software and collaborative activities should support read-write learning via an appropriate subset of the following.

1. **Give increased focus on individual learning.**
2. **Avoid vague, non-specific activities in favour of giving more concrete direction on expectations and deliverables.**
3. **Provide written learning material (lecture notes, handouts, and references to textbooks and manuals).**
4. **Use lists, headings, glossaries and definitions.**
5. **Promote the use of:**
    a. Written directions
    b. Written questions
    c. Well-structured open-ended questions with text response
    d. Essay writing activities
    e. Journaling activities
    f. Word wall activities (wordle)
6. **Allocate reading time.**
7. **Promote activities to write notes, then rewrite and reread repeatedly as a revision tactic.**
8. **Promote activities to rewrite subject ideas and principles using different words.**
9. **Promote activities to reconstruct any visual elements such as diagrams, graphs, charts etc. into textual statements.**
10. **Promote activities to reconstruct actions, events or behaviours into textual statements.**
11. **Promote activities to arrange learning material and notes into titles, hierarchies and points.**
12. **Promote activities to represent list-based learning material into multiple-choice questions.**

The above points can all be implemented via the appropriate design and implementation of the e-learning software and CLE activities; specifically, the use of: note apps, e-portfolios, cloud–based word processors, Wikis, blogging, journals and text chats.

It should be noted that read-write learners often prefer individual learning, so less focus should be given to group and collaborative learning; however, the CLE can still be used for activities such as Wikis, blogging, journals and text chats.

4.7.5.5 Heuristic 16.4: Support Kinaesthetic Modal Preference

Kinaesthetic learners prefer learning that connects to their experience and reality. They are more adept at recalling events and associated feelings, or physical experiences from memory. This experience can be derived from physical activity such as field trips, manipulating objects, and other practical first-hand experience. However, it can also be derived through simulation and the presentation of information strongly tied to experience and reality. Hence, kinaesthetic learning can be multi-modal since the information describing experience and reality can be presented in a visual, aural or read-write form.

As a sub-heuristic of heuristic 16, this heuristic builds upon the research outlined in its parent, but gives more specific focus to kinaesthetic approaches and guidelines, as detailed in research by (Fleming & Mills 1992; Fleming 1995; McCartney et al. 2007; Pritchard 2009; Othman & Amiruddin 2010; Allen et al. 2011; Fleming 2012). Distilling research in this area recommends that the e-learning software and collaborative activities should support kinaesthetic learning via an appropriate subset of the following:

1. **Promote practical activities (experiments) either real or simulated that engage understanding by doing,** i.e. by manipulating objects, building or constructing, or hands-on projects.
2. **Promote learning material directly connected to experience and reality.**
3. **Promote learning based on real-life examples.**
4. **Provide case studies and real-life applications to help with the understanding of principles and abstract concepts.**
5. **Provide questions based on practical activities.**
6. **Provide learning based on live demonstrations.**
7. **Promote activities focused on finding solutions to real-life problems.**
8. **Promote activities that incorporate an element of trial and error.**
9. **Provide learning material that uses exhibits, samples, pictures and photographs that illustrate an idea and tie back to real life.**
10. **Promote activities to recall experiments and physical experiences from memory.**
11. **Promote learning that uses multiple senses, such as sight and hearing, or tries to evoke the senses of touch, taste and smell.**
12. **Promote activities that use previous exam papers and conditions.**

It is important to reaffirm that although kinaesthetic learners learn from real-life and personal experience, and find great value in physical activity, they still derive significant learning value from simulations and other learning that is directly linked to reality or experience. The kinaesthetic learner cannot physically experience everything; what is important is that the sense of experience and reality is conveyed to them. The latter can be aptly provided by educational technology.

4.7.6 ARCS Theory of Motivation

Building on the review of ARCS Theory of Motivation presented in section 2.4.8, this section further discusses ARCS principles, and elaborates on how they are distilled into the e-learning heuristics outlined in Table 19.

ID	Heuristic
14	Use the concepts of Attention, Relevance, Confidence and Satisfaction (ARCS) to attain and sustain learner motivation.
14.1	Use "Attention" grabbing strategies to increase learner motivation.
14.2	Explain the "Relevance" of the learning material to increase motivation.
14.3	Build "Confidence" to increase learner motivation.
14.4	Build "Satisfaction" to increase learner motivation.

Table 19: E-learning heuristics based on ARCS theory of motivation

4.7.6.1 Heuristic 14: Use the Concepts of Attention, Relevance, Confidence and Satisfaction (ARCS) to Attain and Sustain Learner Motivation

Irrespective of the effectiveness of the learning material, without motivation, students are hampered from learning, and whilst motivation cannot be directly controlled, it can be positively influenced. According to the ARCS model, to predictably improve motivation and performance, the instructional material and environment should capture the learners' attention, ensure relevance to the learner, build learner confidence and ensure learner satisfaction.

As a parent heuristic, heuristic 14 distils research in the ARCS motivational model, and recommends that the e-learning software and collaborative activities should consider a balanced subset of the following sub-heuristics:

- 14.1: Use "Attention" grabbing strategies to increase learner motivation.
- 14.2: Explain the "Relevance" of the learning material to increase motivation.
- 14.3: Build "Confidence" to increase learner motivation.
- 14.4: Build "Satisfaction" to increase learner motivation.

Considering the research of (Johnson et al. 1984; Hidi & Harackiewicz 2000; Lepper et al. 2005; Nuutila et al. 2005; Virvou et al. 2005; Schraw et al. 2006; Condie & Munro 2007; Keller 2008; Clark & Ernst 2009; Papastergiou 2009; Shroff & Vogel 2009; Liu et al. 2011; Muntean 2011; de Freitas & de Freitas 2013; Kim et al. 2014; Pirker et al. 2014) the successful implementation of motivational instructional techniques, and specifically the ARCS model, can potentially result in the following educational benefits.

1. A positive impact on learners' interest, engagement, and motivation;
2. Due to the increased learner motivation, a resultant improvement in learning and academic success;
3. An increased likelihood that learners will persevere in difficult situations and approach demanding activities more enthusiastically than less motivated peers;

4. A decrease in dropout rates in distance learning courses from motivated learners; and
5. The emphasis of ARCS heuristics on authentic learning, practice activities and increased learner control can also lead to deeper learning.

For further information on the potential challenges of this parent heuristic, refer to the sub-heuristics listed previously.

4.7.6.2 Heuristic 14.1: Use "Attention" Grabbing Strategies to Increase Learner Motivation

The first step in increasing learner motivation is to capture their attention, and then employ strategies to sustain their attention throughout the learning process. This involves an initial inquiry arousal, stimulating a deeper level of curiosity and then sustaining attention via varied instructional techniques.

This heuristic builds upon the research outlined in its parent (Heuristic 14), but gives specific focus to approaches and guidelines to capture and maintain learner attention. Distilling research in this area by (J. M. Keller 1987a; J. M. Keller 1987b; Lebow 1993; Huffaker & Calvert 2003; Karagiorgi & Symeou 2005; Nuutila et al. 2005; Palmer 2005; Connolly & Stanfield 2006; Schweitzer & Brown 2007; Anderson 2008; Chang & Smith 2008; Keller 2008; Mayer & Griffith 2008; Hattie 2009; Jang 2009; Papastergiou 2009; Shen et al. 2009; Shroff & Vogel 2009; Alsumait & Al-Osaimi 2010; Lee & Choi 2011; Liu et al. 2011; Stuchlikova & Benkovska 2011; Stott & Neustaedter 2013; Pirker et al. 2014) recommends that the instructional design and implementation of the e-learning software and associated collaborative activities should consider an appropriate subset of the following guidelines:

1. **Capture student attention at the start of the learning process.** This can be achieved by stimulating graphics, animations and/or instructional material that invoke:
    a. A sense of wonderment, incongruity, conflict, or personal or emotional resonance with the students.
    b. An orienting reflex based on an unexpected change or novel stimulus that attracts student attention.
    c. A sensation-seeking reflex by stimulating the learners' inherent inclination to pursue sensory pleasure, excitement, and experiences that are varied, novel, complex or intense.
2. **Stimulate a deeper level of curiosity by fostering the learner's inherent nature to explore, discover and understand**.
    a. Instructional material that uses progressive disclosure to maintain suspense and gradually build learning.
    b. Question-based techniques that prompt thinking and inquiry.
    c. Activities that create a paradox or that arouse a sense of mystery, problem-solving, or experiential situations. These in turn encourage a sense of inquiry and knowledge-seeking behaviour.

3. **Maintain attention via variable instructional design:** avoid using the same instructional approaches repeatedly. Instead, include variations in instructional design, presentation style and modality.

The successful implementation of heuristic 14.1, as part of a balanced implementation of all the sub-heuristics of heuristic 14, can potentially result in the educational benefits listed in heuristic 14. However, it is important that this heuristic is implemented with careful and measured instructional design that avoids unnecessary learning material that could in turn increase cognitive load.

4.7.6.3 Heuristic 14.2: Explain the "Relevance" of the Learning Material to Increase Motivation

To ensure that motivation is maintained the learner must perceive the learning material has a personal relevance to them; there must be a "*connection between the instructional environment, which includes content, teaching strategies, and social organization, and the learner's goals, learning styles, and past experiences*" (Keller 2008, p.177).

This heuristic builds upon the research outlined in its parent (Heuristic 14), but gives specific focus to approaches and guidelines to explain the relevance of the learning material to the learners. Distilling research in this area by (Johnson et al. 1984; J. M. Keller 1987a; J. M. Keller 1987b; Schunk 1991; Lebow 1993; Hidi & Harackiewicz 2000; Huffaker & Calvert 2003; Keller & Suzuki 2004; Nuutila et al. 2005; Palmer 2005; Connolly & Stanfield 2006; Nicol & Macfarlane-Dick 2006; Schraw et al. 2006; Condie & Munro 2007; Long 2007; Schweitzer & Brown 2007; Anderson 2008; Chang & Smith 2008; Keller 2008; Zhang & Bonk 2008; Clark & Ernst 2009; Papastergiou 2009; Shroff & Vogel 2009; Alsumait & Al-Osaimi 2010; Hadjerrouit 2010; Anderman & Dawson 2011; Lee & Choi 2011; Nicholson 2012; Stott & Neustaedter 2013; Morrison & DiSalvo 2014) recommends that the instructional design and implementation of the e-learning software and associated collaborative activities should consider an appropriate subset of the following guidelines:

1. **Aligning with Learner Goals** - The learning material reflects an understanding of the learners' needs and demonstrates how the new knowledge or skills will support them in achieving their goals.
    a. Communicate clear learning goals that answer: Why should I learn this? What is the importance of this learning material? How can I use this new knowledge in real-life situations?
    b. Communicate how the learning material and learning goals are related to the learners' goals.
    c. Focus on intrinsic goal orientation in which the learners are engaged in learning that is personally interesting and freely chosen.
    d. Where intrinsic goal orientation is a challenge, then extrinsic goals can be used to tie learning to an external factor such as earning a reward, passing an exam, college acceptance, etc.
    e. Ask learners to explain their own perceptions of relevance.

2. **Aligning with Learning Styles** - A secondary or supplementary approach in establishing relevance is related to how something is taught rather than to the substance of what is being taught.
    a. Use a variety of pedagogical strategies, such as individual activities and strategies that focus on cooperative group work, thereby appealing to both learners that prefer individual work and those that need affiliation.
    b. Use a multi-modal approach to appeal to the full range of modal preferences (heuristic 16).
3. **Aligning with what is Familiar** – Engage the students on a personal level and relate the learning material back to the learner's real life.
    a. Engage the learners on a personal level by using their names and asking them for their experience, examples and ideas.
    b. Use authentic learning approaches that connect the learning material to intrinsically interesting topics relevant to the learner's current situation or future aspirations.

The successful implementation of heuristic 14.2, as part of a balanced implementation of all the sub-heuristics of heuristic 14, can potentially result in the educational benefits listed in heuristic 14. However, it should be noted that with e-learning software, as opposed to a classroom environment where the teacher is dynamically interacting with students, there is an increased challenge in building a personalised learning profile of the learner's individual goals and motives. As such, the learning profile is typically generalised based on the target audience and the learner analysis undertaken at the start of the motivational design process.

4.7.6.4 Heuristic 14.3: Build "Confidence" to Increase Learner Motivation

Building learners' confidence in their ability to learn also increases their motivation to learn; any learned helplessness or fear of the topic, skill or environment that hinders learning should be addressed and replaced by an expectation of success. The positive expectancy for success should then be followed promptly by actual success that the learners can clearly attribute to their own abilities and effort.

This heuristic builds upon the research outlined in its parent (Heuristic 14), but gives specific focus to approaches and guidelines to build learner confidence. Distilling research in this area by (J. M. Keller 1987a; J. M. Keller 1987b; Schunk 1991; Lebow 1993; Black & Wiliam 1998; Sweller et al. 1998; Jonassen 1999; Hidi & Harackiewicz 2000; Keller & Suzuki 2004; Karagiorgi & Symeou 2005; Palmer 2005; Connolly & Stanfield 2006; Nicol & Macfarlane-Dick 2006; Schraw et al. 2006; Condie & Munro 2007; Anderson 2008; Chang & Smith 2008; Keller 2008; Black & Wiliam 2009; Clark & Ernst 2009; Hattie 2009; Papastergiou 2009; Shen et al. 2009; Shroff & Vogel 2009; Alsumait & Al-Osaimi 2010; Corbalan et al. 2010; Hadjerrouit 2010; Anderman & Dawson 2011; Liu et al. 2011; Nicholson 2012; de Freitas & de Freitas 2013; Stott & Neustaedter 2013; Kim et al. 2014; Morrison & DiSalvo 2014; Pirker et al. 2014) recommends that the instructional design and implementation of the e-learning software and associated collaborative activities should consider an appropriate subset of the following guidelines:

1. **Establish trust and positive expectations for learning success:**

   a. Inform the learners of what is expected from them by explaining the requirements for success and the evaluation criteria.
   b. Address any fear or anxiety held by the learners.
   c. If using a progressive disclosure strategy, the above points will need to be softened to not remove suspense.
   d. Provide ongoing encouragement (coaching) to complete the lesson.

2. **Provide opportunities for meaningful success:**
   a. Opportunities for success should be provided as soon as possible in the lesson.
   b. Meaningful success is contingent on there being enough challenge to require a degree of effort to succeed, but not so much that it creates serious anxiety.
   c. The success must be clearly attributable to the learner's efforts and ability rather than to luck or the task being too easy.
   d. If the learning material is new, the level of challenge should be relatively modest and combined with frequent feedback that confirms the learner's success or helps the learner progress towards success.
   e. When the basics are mastered, progress to higher levels of challenge that help learners exercise and sharpen their skills.
   f. Pacing should be adjusted as competency levels change; typically, success activities should move quickly from simple to complex, or known to unknown, to avoid boredom, but not so quickly that learners become anxious.
3. **Balance a stable e-learning environment with the learners' need to feel in control and responsible for their success:**
   a. Provide a stable learning environment that sets the standards expected and guides the learning experience.
   b. Within that stable learning environment, allow the learners as much personal control (as possible) over their actual learning experience. Techniques that support such personal control are:
      i. Fostering an environment where it is all right to make mistakes and learn from them.
      ii. Using learning activities and problem-based methods that require the learner to exercise personal control and judgement to solve.
      iii. Providing corrective feedback that helps the learner see the cause of their mistake and allows them to learn and retry.

The successful implementation of heuristic 14.3, as part of a balanced implementation of all the sub-heuristics of heuristic 14, can potentially result in the educational benefits listed in heuristic 14. However, e-Learning software used in isolation, without teacher involvement, cannot effectively address learners' fear and anxieties. Furthermore, the instructional design of the e-learning software will require careful balance in the following areas:

- The guideline to explain to learners the learning objectives, requirements for success and the evaluation criteria may need to be mitigated when using progressive disclosure techniques and problem-based learning (Heuristic 4).
- The criteria related to giving learners personal control in their learning needs to be balanced against the provision of a stable learning environment (Heuristics 21, 21.1).
- The provision of success opportunities creates a challenge to move quickly enough to avoid boredom, but not so quickly that learners become anxious.

4.7.6.5 Heuristic 14.4: Build "Satisfaction" to Increase Learner Motivation

Once motivation is inspired in the learner, it needs to be maintained by providing the learner with a sense of satisfaction with the process and/or results of the learning experience. This is achieved by a combination of intrinsic methods, extrinsic reinforcement, and a sense of fairness in the learning results.

This heuristic builds upon the research outlined in its parent (Heuristic 14), but gives specific focus to approaches and guidelines to build learner satisfaction. Distilling research in this area by (Johnson et al. 1984; J. M. Keller 1987a; J. M. Keller 1987b; Schunk 1991; Lebow 1993; Jonassen 1999; Hidi & Harackiewicz 2000; Huffaker & Calvert 2003; Keller & Suzuki 2004; Karagiorgi & Symeou 2005; Nuutila et al. 2005; Palmer 2005; Connolly & Stanfield 2006; Nicol & Macfarlane-Dick 2006; Schraw et al. 2006; Condie & Munro 2007; Long 2007; Schweitzer & Brown 2007; Anderson 2008; Chang & Smith 2008; Keller 2008; Clark & Ernst 2009; Hattie 2009; Jang 2009; Papastergiou 2009; Shen et al. 2009; Shroff & Vogel 2009; Alsumait & Al-Osaimi 2010; Boyle et al. 2010; Hadjerrouit 2010; Anderman & Dawson 2011; Liu et al. 2011; Muntean 2011; Bertacchini et al. 2012; Nicholson 2012; Yang & Chang 2012; de Freitas & de Freitas 2013; Stott & Neustaedter 2013; Pirker et al. 2014; Aritajati et al. 2015) recommends that the instructional design and implementation of the e-learning software and associated collaborative activities should consider an appropriate subset of the following guidelines:

1. **Use intrinsically motivational learning experiences.**
    a. Provide meaningful opportunities for learners to use their newly-acquired knowledge and skills. These opportunities typically have the following characteristics:
        i. They are authentic problems, simulations, or worked examples that allow learners to apply what they have learnt and help to transfer from classroom to real-life.
        ii. They focus on providing the learner with the intrinsic satisfaction that they have mastered the learning.
        iii. They are typically scheduled towards the end of the lesson or the course.
    b. Provide opportunities for learners to coordinate, collaborate, and interact with other learners.
    c. Provide opportunities for learners to have their views heard and respected.
    d. Encourage in learners a sense of control over their learning experience.

e. Support learners in seeing how the various pieces of the learning experience fit together holistically.

2. **Provide positive extrinsic reinforcement to learners' successes.**
    a. Extrinsic reinforcement can be used to supplement, but not replace, intrinsic motivational approaches; both should be used in combination.
    b. Extrinsic reinforcement includes the use of opportunities for advancement, verbal praise, certificates, and any real or symbolic rewards and incentives that provide external recognition of achievement.
3. **Ensure learners perceive the learning process, assessment, and rewards as being fair.**
    a. Ensure that course outcomes are consistent with the initial presentation of course purpose and expectations.
    b. Assessment results and extrinsic reinforcements are not seen in isolation or in terms of absolute value. They need to be consistent, commensurate with the efforts expended in the learning, and comparatively fair in relation to learning peers.

The successful implementation of heuristic 14.4, as part of a balanced implementation of all the sub-heuristics of heuristic 14, can potentially result in the educational benefits listed in heuristic 14. However, with reference to guideline-1.b, as noted in heuristic 11, collaborative activities are not appropriate in all circumstances, and therefore should not be considered to always lead to increased satisfaction.

4.7.7 Cognitive Load

Building on the review of cognitive load theory (CLT) presented in section 2.4.9, this section further discusses CLT research and elaborates on how it is distilled into the e-learning heuristics outlined in Table 20.

ID	Heuristic
17	Integrate words and graphics together, instead of words alone.
17.1	Apply contiguity by aligning words (audio or screen text) with corresponding graphics.
17.2	Representing words as audio, on-screen text or both
18	Avoid adding learning content that does not directly support your instructional goal.
19	Optimise essential processing by segmenting learning material and providing pre-training.
20	Use a conversational style in screen text and audio narration.
21	Provide restricted navigational control in the e-learning software.
21.1	Provide consistent navigational elements and signposts for learning.

Table 20: E-learning heuristics based on cognitive load theory

4.7.7.1 Heuristic 17: Integrate Words and Graphics Together, Instead of Words Alone

An important part of active processing is to mentally construct visual and text representations of learning material, and to mentally connect them. The e-learning software should therefore include both words (audio or screen text) and graphics (static illustrations, animations or videos) to support learners in developing their mental models. The visual elements should not be treated as an afterthought after the text has been written; instead, multimedia lessons should contain words and corresponding visuals that work together to explain the learning content. These visual elements must represent the critical information and relationships in the learning material, and be designed in consideration of the cognitive processes necessary for deep learning.

The integration of words and graphics together to support learning is commonly known as the multimedia principle, and is detailed in research by (Mayer 1989; Chandler & Sweller 1991; Alonso et al. 2005; Fletcher & Tobias 2005; Butcher 2006; McCrudden & Schraw 2007; Clark & Mayer 2011; Clark et al. 2011). Distilling research in this area recommends that the e-learning software and collaborative activities should consider the following guidelines: visual elements[27] should be integrated with accompanying aural or printed text; a variety of graphical types[28] can be used in accordance with the intended learning objectives (refer to Vol 2 Appendix E section B.7 for a brief description of these graphical types); and visual elements should be used to provide navigational support and signposts for learning.

The implementation of the multimedia principle as compared to learning from words only leads to education benefits such as: improved learning performance; a deeper understanding, in which knowledge is encoded and remembered better; being particularly relevant for scientific and technical learning that can be complex; and being especially important for novice learners (with low domain knowledge) who are less experienced in creating their own mental models.

It should be noted that the implementation of this heuristic is further governed by two sub-heuristics:

- 17.1 Apply contiguity by aligning words (audio or screen text) with corresponding graphics.
- 17.2 Representing words as audio, on-screen text, or both

In addition, guideline-3 of this heuristic refers to visual elements providing navigational support and signposts for learning, this is elaborated in sub-heuristic 21.1.

4.7.7.2 Heuristic 17.1: Apply Contiguity by Aligning Words (Audio or Screen Text) with Corresponding Graphics

Building on heuristic 17, it is important to avoid learning material that requires learners to split their attention between, and mentally integrate, multiple sources of information (Ayres & Sweller 2005). The process of integrating distinct sources of information creates an extraneous cognitive load that can be avoided by aligning and integrating words (audio or screen text) in close proximity (i.e. contiguous) to corresponding graphics.

The theoretical foundations of this heuristic are based on the split-attention (contiguity) principle that is detailed in research by (Mayer 1989; Chandler & Sweller 1991; Sweller et al. 1998; Moreno & Mayer 1999;

[27] Illustrations, diagrams, photographs, maps, concept-maps, charts and graphs, animations, videos, etc.

[28] Representative, organisational, relational, transformative, interpretative and decorative.

Kalyuga & Ayres 2003; Sweller 2004; Alonso et al. 2005; Ayres & Sweller 2005; Fletcher & Tobias 2005; Mayer 2005; Kester et al. 2006; Clark et al. 2006; Clark & Mayer 2011). Distilling research in this area recommends that the e-learning software and collaborative activities should support contiguity via the following guidelines:

1. **For contiguity to apply, the multiple sources of information are essential for understanding, and difficult to understand in isolation.** Careful consideration must be given to the logical relation between the information: whether the information is complex, whether understanding is possible without integration, whether integration is negated by the learners' experience level, and whether the same information is being presented redundantly.
2. **Place printed words near corresponding graphics.** Text should not be placed above or below the corresponding graphic, but as close as possible to (even in) the graphic. When parts of an object are being described, place the text close by and, where necessary, use a pointed line to connect. When a process is being described, number and place the text close by and, where necessary, use a pointed line to connect.
3. **Avoid the overuse of text.** Long passages and too much text can become discouraging for many learners. This should be avoided by using multiple editing iterations to cut down the text to the bare essence. Tips on how to reduce unnecessary text are outlined in Vol 2 Appendix E section B.9.
4. **Synchronise spoken words with corresponding graphics.** A spoken word narration that describes an animation or video should play at the same time and be temporally synchronised with the corresponding animation or video. Providing separate controls for the audio and video or providing the audio and video in succession should be avoided.

To reflect this heuristic an example of contiguity is presented by Mayer (1989, p.241) in Figure 19.

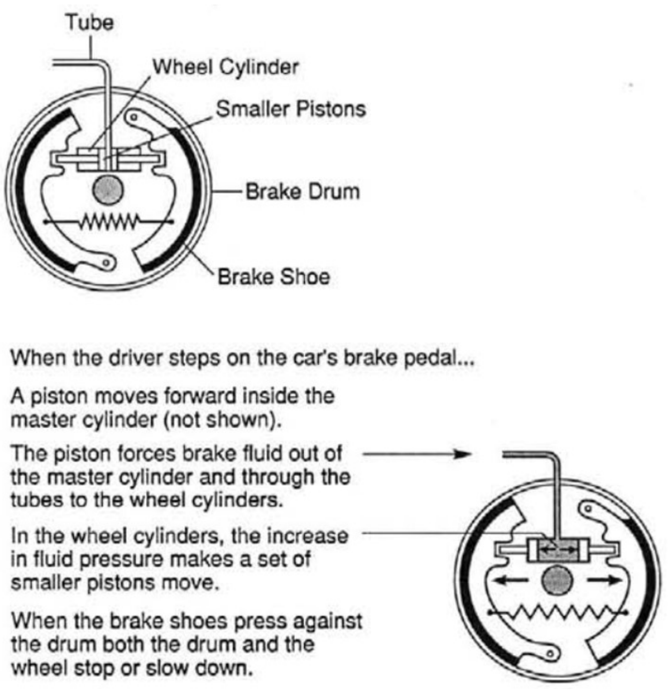


Figure 19: Example of contiguity - Illustration of hydraulic braking system

The successful implementation of this heuristic reduces extraneous cognitive load by removing the need for learners to mentally integrate disparate learning sources. This in turn allows the learner to focus their cognitive resources on understanding the learning material. Furthermore, by integrating learning material in this manner, they are held together in working memory, therefore making a meaningful connection between them. This in turn is fundamental to the sense-making process that leads to deeper learning.

A challenge with this heuristic is when the student is expected to **simultaneously** focus on written text and graphics, this can in turn lead to cognitive overload; guidance for this scenario is detailed in heuristic 17.2.

In addition, it should be noted that this heuristic is most beneficial to low-knowledge learners needing support in developing their mental models and is impacted by the expertise reversal effect, whereby experienced learners cannot avoid the integrated format, which in turn can interfere with existing mental models (Moreno & Mayer 1999; Kalyuga & Ayres 2003).

4.7.7.3 Heuristic 17.2: Representing Words as Audio, On-screen Text, or Both

When words accompany visual elements, and both require the learner's simultaneous attention, it is typically better to present the words as audio instead of on-screen text. This avoids cognitive overload (refer to Figure 20) by balancing the learning material across two separate cognitive channels - words in the auditory channel and graphics in the visual channel (the modality principle). Furthermore, it is typically recommended to not duplicate words via audio and screen text (the redundancy principle). This avoids situations where the learner focuses too much on-screen text to the detriment of the graphics, or potentially focusing on the screen text and narration and comparing whether they are equivalent (refer to Figure 21).

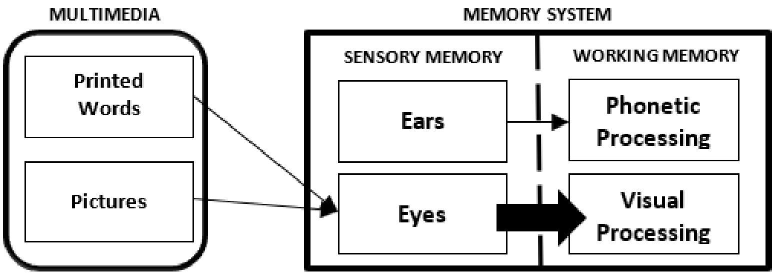


Figure 20: Overload of visual channel with presentation of screen text and graphics.

Source (Clark & Mayer 2011, p.122).

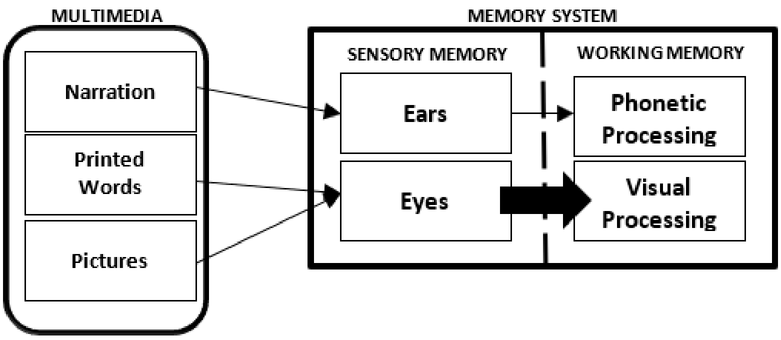


Figure 21: Overload of visual channel with graphics explained by words in audio and screen text.

Adapted from (Clark & Mayer 2011, p.123).

The modality and redundancy principles are detailed in research by (Sweller et al. 1998; Kalyuga 1999; Moreno & Mayer 1999; Kalyuga et al. 2000; Mayer et al. 2001; Craig et al. 2002; Moreno & Mayer 2002; Kalyuga & Ayres 2003; Mayer et al. 2003; Mayer & Moreno 2003; Mayer 2005; Ginns 2006; Harskamp et al. 2007; Jamet & Le Bohec 2007; Lee et al. 2008; Mayer & Johnson 2008; Clark et al. 2006; Clark & Mayer 2011). Distilling research in this area recommends an increased focus on applying audio narration with visual elements, but also requires more discerning decision making in identifying when on-screen text remains the best learning option. The following guidelines apply:

1. **When explaining graphical elements, it is better to avoid duplicating words in both audio and screen text.**
2. **Words communicated in audio form should be preferred over on-screen text if the text needs to be synchronised with more dynamic visual elements**, such as animations, videos, or a series of static frames.
3. **The audio material must be clear and concise, and synchronised with the visual learning material.**
4. **When you do not have a simultaneous graphical presentation then modality does not apply**, and screen text can be presented alone, or simultaneously with audio.

However, exceptions to these guidelines do apply (Kalyuga 1999; Moreno & Mayer 2002; Mayer & Johnson 2008; Clark & Mayer 2011):

5. **In some scenarios, keywords should still be highlighted on screen with visual elements** to act as a graphical organiser, and to direct the learner's attention. This aids retention.
6. **With certain learning contexts and learning material, screen text should be preferred even if there is a simultaneous graphical presentation**. For instance:
    a. When words should remain available to the learner over time.
    b. When the words are technical, unfamiliar or formulae.
    c. When the words are not in the learners' native language.
    d. When lengthy text is being presented or is necessary for future reference.
    e. When the text lists key steps in a procedure or gives directions in a practical exercise.
7. **There remain some conditions when the use of redundant on-screen text in conjunction with audio narration can give learning benefits**:
    a. When there is no graphical element, you may decide to have narration and some text, therefore using dual channels and not overloading either.
    b. The scenarios listed in point 6.
    c. When the learning material is not complex, or there is ample time to process the visual elements; for instance, when text and graphics are presented sequentially or when the pace of the presentation is sufficiently slow.

The successful implementation of this heuristic efficiently utilises dual channels to integrate learning material in a manner that reduces cognitive load and supports retention and deep learning. However, as noted in the previous sub-heuristic, it is most beneficial for low knowledge learners, and is susceptible to the expertise reversal effect (Moreno & Mayer 1999; Kalyuga et al. 2000; Kalyuga & Ayres 2003; Harskamp et al. 2007).

Additionally, increased focus on audio material involves some additional practical challenges, such as: introducing too much noise into the learning environment; adding cost and potential delay to the development process; and is comparatively restrictive in supporting quick and easy changes when learning material changes.

4.7.7.4 Heuristic 18: Avoid Adding Learning Content that does not Directly Support your Instructional Goal

Considering humans limited cognitive capacity, it is seemingly intuitive and evident that learning content should be focused on directly supporting the instructional goals. However, frequently there is a strong implicit temptation to add extra material in e-learning that will either grab student attention and keep them engaged, or add extra explanatory detail that is nonessential. This can lead to interesting but unnecessary learning material, the use of overly dramatic stories and examples, and gratuitous use of text, audio, visual and multimedia elements, which in turn can harm the learning process.

This heuristic is founded on research into the arousal effect[29], coherence principle and seductive details effect as detailed in research by (Chandler & Sweller 1991; Harp & Mayer 1998; Moreno & Mayer 2000a; Mayer et al. 2001; Mayer et al. 2003; Mayer & Moreno 2003; Alonso et al. 2005; Sanchez & Wiley 2006; Lehman & Schraw 2007; Mayer & Griffith 2008; Clark & Mayer 2011). The inclusion of extraneous learning material can sap limited cognitive capacity and interfere with the learner's endeavour to make sense of the learning material by a combination of distraction, disruption and diversion (Harp & Mayer 1998; Mayer et al. 2001; Mayer & Griffith 2008; Clark & Mayer 2011):

1. Seductive details **distract** limited attention away from the main ideas of the learning material;
2. Seductive details **disrupt** and interfere with the construction of an organised mental model (schema) by introducing noise (unnecessary learning material) into the learning process;
3. Seductive details **divert** correct schema integration by activating inappropriate prior knowledge, which is then used to incorrectly organise the incoming learning material.

However, research findings from Mayer and Griffith (2008) give greater credence to diversion being the underlying cause for negative learning impact.

Distilling research in this area (Harp & Mayer 1998; Kalyuga et al. 2000; Moreno & Mayer 2000a; Moreno & Mayer 2000b; Knez & Hygge 2002; Sanchez & Wiley 2006; Lehman & Schraw 2007; Clark et al. 2011;

[29] The arousal effect theorises that the inclusion of entertaining and interesting material causes learners to become more emotionally aroused, and therefore work harder to learn the material (Mayer et al. 2001).

Clark & Mayer 2011) promotes an increased focus on learning material that is concise and focused on the intended learning outcomes, via the following guidelines:

1. **The learning material should not be embellished with unnecessary detail**, or with graphics, audio, text or multimedia that focus only on creating interest.
2. **The interest and engagement should come from the core learning content and instructional design**.
3. **Avoid the addition of environment sounds and / or background music** since it can lead to a reduction in learning retention and transfer.
4. **Avoid pictures and graphics that are purely decorative** since they will not lead to improved learning.
5. **Avoid visual elements that are somewhat (indirectly or tentatively) related to learning objectives** since they disrupt the learning process.
6. **Use simpler visuals.** Simpler visuals include visuals with fewer details presented at one time.
7. **Avoid adding extraneous text with embellished textual or narrative descriptions** in preference to concise focused text or narrative.
8. **Avoid lengthy audio-visual material** which can cause learner frustration from having to view and/or listen through all the material to extract the relevant learning.

The avoidance of unnecessary, embellished, overly detailed or decorative learning content enables a truer focus on instructional goals that, in turn, positively influences both recall and deep cognitive processing of learning material. However, due concern should be taken in instructional design to balance constructivist principles, and the need to gain the learner's attention, against the possibility of causing cognitive overload.

4.7.7.5 Heuristic 19: Optimise Essential Processing by Segmenting Learning Material and Providing Pre-training

As discussed in section 2.4.9, in cognitive learning theory, essential processing reflects the learning processes used by the student to understand the core learning material. It is fundamental to the learning process, but can be greatly impacted by the inherent complexity of the material. Complex learning material can overwhelm the learner's working memory to the extent that they do not have enough remaining processing capacity to mentally organise the incoming material and integrate it with existing schemas (deep learning and far transfer).

Learning complexity is discussed by (Pollock et al. 2002; Kalyuga & Ayres 2003; Sweller 2004; Jonassen & Hung 2008; Clark & Mayer 2011) as being a product of the number of individual elements of information to be processed, and the number of interrelationships between these elements that also need to be processed. Therefore, rather than treating complex learning material as a whole; deep learning is more effectively supported by managing complexity via two approaches: segmenting breaks a lesson into manageable segments that do not overload the student's cognitive processes; and pre-training provides foundation information that gives names and characteristics of key concepts that can be built upon and used in the main learning segments.

Concepts of segmenting and pre-training have been studied by (Mayer & Chandler 2001; Pollock et al. 2002; Mayer & Moreno 2003; Mayer et al. 2003; Sweller 2004; Kester et al. 2006; Moreno 2007; Moreno & Mayer 2007; Anderson 2008; Clark & Mayer 2011; Clark et al. 2011) and have been distilled into the following guidelines:

1. **Provide a stable foundation for learning by giving pre-training which orients the learner and explains terminology and pre-requisite concepts.** Even when learning material is segmented, it can sometimes still be complex or introduce a lot of unfamiliar terms or concepts. The pre-training principle reduces this complexity by giving the learner an orientation which explains terminology or pre-requisite concepts. In effect, this redistributes some of the student's essential processing from the main lesson to the pre-training, and provides a stable foundation for the student to build their learning on.
2. **Break learning material into smaller segments and present them sequentially.** Segmenting helps the learner manage complexity by breaking the lesson into smaller pieces that convey just two or three steps in the process, or describe just two or three major relations between elements. These segments are then presented sequentially, under the learner's controlled progress, which in turn allows the learner to digest the material at their own pace.

In addition, based on qualitative findings from this study (refer to section 6.5), segmented learning material can be organised into metaphorical chapters. To help transition students to new e-learning concepts it can be helpful to mimic approaches they know and feel comfortable with. The e-learning software can be structured as chapters, complete with learning objectives, learning material, an end of chapter summary, and end of chapter review questions.

The implementation of this heuristic does not necessarily lead to improvements in immediate learning performance (retention) but improves deep learning (understanding) and supports improved learning as measured in learning transfer tests. In addition, using metaphorical chapters gives structure to the learning experience, and using the chapter summary and review questions reasserts to learners the important learning material necessary for the examinable curriculum.

However, it should be noted that this heuristic is most effective with students who are beginners in the subject area. More expert learners, able to call upon a robust set of schemas on the subject matter, are more adept at managing the complexity and integrating the new learning into their schemas.

To some extent, segmenting learning material and structuring it into chapters goes against constructivist and connectivist principles, and the discovery inherent in problem-based learning. However, this pedagogy proposes a balance between extremes and seemingly incompatible approaches. Moderate approaches should be used that can marry aspects of constructivism and problem-based learning within a more structured e-learning environment. For example, guided discovery can be used in which problem-based learning is supported by macro-scaffolding (pre-training) on how the problem should be approached, and just-in-time delivery of segmented learning material to support problem resolution.

4.7.7.6 Heuristic 20: Use a Conversational Style in Screen Text and Audio Narration

Psychology research has shown that personalised messages can promote deep learning by actively engaging students; learners work harder to understand material when they feel they are in a conversation, rather than being presented with information. The conversational style works on two levels: it presents the information; but also primes the appropriate cognitive processes to motivate the learner to try to make sense of the learning material. It is therefore recommended that the e-learning software should use a conversational style (using first- and second-person and active language) in both screen text and audio narration, and should avoid the use of formal and passive voice.

Research by (Moreno & Mayer 2000b; Moreno 2004; Moreno & Mayer 2004; Moreno & Mayer 2007; Clark & Mayer 2011) extend to multimedia learning a wide body of psychology research into the self-referential effect. The self-referential effect theorises that people react differently to situations that involve personal reference, and that information recall and understanding is improved when it is encoded with respect to themselves rather than a different frame of reference. Building on this research, this heuristic recommends that the copywriting of the screen text and audio narration in the e-learning software and CLE activities should consider the following guidelines:

1. **Use a more informal conversational style in narration and screen text to give learners a sense that they are in a conversation with a partner**; this motivates learners to work harder to understand the material.
2. **The conversational tone and style mean using words like "I", "we" and "you"**.
3. **Words and phrasing should be less formal but without reducing the importance of the learning material**.
4. **Do not overuse the conversational style to the point it becomes a distraction to learning**; it should remain polite, friendly and respectful, whilst not degenerating into slang and /or colloquialisms.
5. **In an audio narration, make sure the voice of the narration is human with a standard accent** instead of a computer-generated voice.

Adjusting text and narration to be more conversational, has been shown to increase engagement and improve comprehension (deep learning) by enabling learners to interpret and interrelate information in familiar conversation versus abstract instruction. Although results from multimedia research in this area are mixed, conversational style has also been shown in some studies to improve retention.

4.7.7.7 Heuristic 21: Provide Restricted Navigational Control in the E-learning Software

Learner control is implemented by navigational features that allow the learner to choose the path they take through the e-learning software by selecting the topics and instructional elements they prefer, and the pace at which they undertake learning. The tacit expectation is that more learner control will improve learning and will satisfy the learner's desire for more control. However, the challenge is that often learners may not have enough self-awareness and meta-cognitive skills to accurately judge what they already know, what they need to learn, and which instructional elements (with learning value) to select. In consideration of the high-school age-group, this pedagogy recommends a restricted level of navigational control that focuses more towards program control. However, within a structured e-learning environment, the learner must still be given freedom in several key areas that are outlined in the guidelines below.

Research by (Squires & Preece 1999; Mayer et al. 2003; Moreno & Mayer 2007; Clark & Mayer 2011; Clark et al. 2011; Kalyuga et al. 2000; Mayer & Chandler 2001) give guidance in setting stable learner interactions, within the e-learning environment and navigational control, for improved learning performance. This is distilled into the following guidelines:

1. **Restrict learners' ability to control the order of lessons, topics and screens within the e-learning software, but allow the previously covered material to be revisited.**
2. **Display all important educational material as default to avoid it being skipped by the learner.**
3. **Allow learners the flexibility to learn at their own pace.**
4. **Balance a stable e-learning environment with the learners' need to feel in control and responsible for their success.** In consideration of heuristic 14.3 guideline-3, it is critical that within a stable learning environment, learners must still be allowed as much personal control (as possible) over their actual learning experience, such as: fostering an environment where it is acceptable to make mistakes and learn from them; using learning activities and problem-based methods that require the learner to exercise personal control and judgement to solve; providing corrective feedback that helps the learner see the cause of their mistakes; and allowing them to learn and retry.

It must be considered that this heuristic is subject to the expertise reversal effect in that experienced learners who have prior knowledge and skills in the subject matter, or good metacognitive skills, or who are taking an advanced lesson or course, can be given increased learner control to support effective learning.

A further consideration in relation to program control is heuristic 10 and supporting the learners' Zone of Proximal Development via adaptive control. Adaptive Control entails the e-learning software dynamically adjusting lesson difficulty and support, based on an evaluation of ongoing learner responses. This offers personalised instruction to the learner and, to some extent, can be used to mitigate the aforementioned expertise reversal effect.

The benefits from focusing the e-learning software towards program control rather than learner control are that:

1. It reduces the extraneous cognitive load of the learner having to accurately understand their learning needs and plan their path through the e-learning software,

2. With learner control, low prior knowledge learners may choose to view up to 50% fewer learning screens.
3. Low prior knowledge learners typically perform worse under learner control; whilst high prior knowledge learners typically perform equally well under both scenarios.

4.7.7.8 Heuristic 21.1: Provide Consistent Navigational Elements and Signposts for Learning

Building on heuristic 21, sub-heuristic 21.1 further reinforces the stable and structured e-learning environment, by providing consistent and meaningful navigational elements and signposts for learning. The e-learning software should provide a clear and consistent Graphical User Interface (GUI) that places minimal cognitive demand on the learner, and intuitively supports learning. One important part of this is to provide clear navigational elements and visual cues (signposts) of the learning material that emphasises recognition rather than recall.

A pre-existing body of research in this area has been supplemented in more recent times by research by (Harp & Mayer 1998; Kalyuga 1999; Squires & Preece 1999; Mayer & Moreno 2003; Moreno 2007; Mayer & Griffith 2008; Mayer & Johnson 2008; Clark & Mayer 2011); this has been distilled into the following e-learning guidelines:

1. **Provide a clear, consistent and meaningful navigational interface** (navigational menus, movement buttons, course maps, multimedia controls, etc.) that allow the learner to intuitively progress through the e-learning software and control the educational material.
2. **Provide clear, consistent and meaningful signposts for learning**, such as a course map, learning objectives, screen titles, embedded topic headers, labels, summaries, links (including summary previews), etc.
3. **Ensure pre-training and/or a guide is provided to learners** that explains the navigational interface and learning signposts.

The successful implementation of this heuristic enables a consistent and intuitive e-learning interface that is innately meaningful and supports the learning experience without creating an additional and unnecessary burden on cognitive load. Furthermore, meaningful signalling can be used to help the learner to select and mentally organise the learning material, thereby improving retention and comprehension. However, it should be noted that some studies have not demonstrated improved learning from signalling approaches when used in conjunction with extraneous learning material (Harp & Mayer 1998; Moreno 2007; Mayer & Griffith 2008).

4.7.8 Gamification

Building on the review of gamification presented in section 2.4.10, this section further discusses gamification research, and elaborates on how it is distilled into the e-learning heuristics outlined in Table 21.

ID	Heuristic
15	Use gamification to increase motivation and learning performance.
15.1	Integrate gamification elements tightly within existing learning processes.
15.2	Build extrinsic gamification elements on top of existing learning processes.

Table 21: E-learning heuristics based on gamification

4.7.8.1 Heuristic 15: Use Gamification to Increase Motivation and Learning Performance

In the context of e-learning, gamification is the use of game design elements within e-learning software to increase the pleasure, fun, and motivation in the learning process, and to encourage positive learning behaviour. Game design elements must be tightly integrated with existing intrinsically motivational aspects of the software. Suggested game design elements include: points, leaderboards, achievements/badges, levels, rewards, progression, challenge, storytelling, clear goals, rapid feedback, explanatory feedback, freedom to fail, etc. The implementation of gamification can be broadly split into two high-level guidelines that are discussed in detail as separate sub-heuristics:

- 15.1: Integrate gamification elements tightly with existing learning processes.
- 15.2: Build extrinsic gamification elements on top of existing learning processes.

The overriding benefit of gamification is to create a gameful and playful learning experience that motivates the intended learning behaviour, and generally increases engagement and the joy of use. Gamification attempts to build upon social psychological processes such as self-efficacy, group identification, and social approval to provide learning rewards that motivate continued good work.

Various studies (Papastergiou 2009; Muntean 2011; Deterding 2012; de Freitas & de Freitas 2013; Decker & Lawley 2013; Hamari et al. 2014; Iosup & Epema 2014; Morrison & DiSalvo 2014) cite that gamification provides positive effects on motivation, and ultimately on learning performance. However, the findings from previous studies have some variation in results and some shortcomings in research design that leave some doubt. Current implementations of gamification often focus too heavily on the points and rewards systems from games (guideline-2) and ignore intrinsically motivational aspects (guideline-1). This approach can in fact be detrimental to the learning process by reducing the learner’s own internal motivation (Nicholson 2012; Decker & Lawley 2013; Deterding et al. 2013; Stott & Neustaedter 2013; Morrison & DiSalvo 2014).

It is also cautioned (de Freitas & de Freitas 2013; Decker & Lawley 2013; Iosup & Epema 2014; Morrison & DiSalvo 2014; Pirker et al. 2014) that meaningful gamification is a difficult non-trivial task that increases teacher effort, is time consuming, is likely to require computer-assisted management, and may increase student focus on aesthetics.

Furthermore, it is postulated (Nicholson 2012) that once applied, the removal of extrinsic gamification elements may have a detrimental effect due to the loss of earned badges and points, and the dependency on external motivators. Finally, there is some caution that the positive results of gamification may not be long term, and are in fact caused by a novelty effect.

4.7.8.2 Heuristic 15.1: Integrate Gamification Elements Tightly within Existing Learning Processes

Many aspects of good game design correlate with existing pedagogical practices; therefore, they should already exist within the instructional design of the e-learning software. These should not be reinvented for gamification purposes; instead, gamification elements should simply integrate with the existing pedagogical elements. These pedagogical elements include: storytelling, progressive challenge, intrinsically motivational activities, rapid explanatory feedback, tutorials on how to use (play), and social interaction.

Research by (Vygotsky 1978; Papastergiou 2009; Deterding et al. 2011; Kim 2011; Muntean 2011; Deterding 2012; IVETIC & Petrović 2012; Nicholson 2012; Wu et al. 2012; de Freitas & de Freitas 2013; Stott & Neustaedter 2013; Hamari et al. 2014; Iosup & Epema 2014; Morrison & DiSalvo 2014; Pirker et al. 2014; TechnologyAdvice 2014) is synthesised into the following guidelines that are already present in the pedagogical heuristics:

1. **Gamified learning should offer progression and progressive challenge.** As with all good games, there needs to be progression and progressive challenge as the learner moves from novice to expert, and eventually to master. The level of challenge needs to be enough to avoid boredom, but not so much that its causes frustration or demotivation (Heuristics 8, 10, 14.3 guideline 2, 14.4 guideline 1).
2. **Gamified learning should offer an engaging story.** As with all good games, there needs to be a surrounding story (context) and narrative that the player can engage in; likewise, people learn better when the educational material is embedded in a story they can relate to. A unifying story should be used throughout a curriculum to put learning into a realistic context in which actions and tasks can be practised (Heuristics 1, 1.1, 4, 6.2, 14.1 guideline-2, 14.2 guideline-3).
3. **Gamified learning should allow learners the freedom to fail and provide rapid feedback to support learning.** Games offer a fictional environment in which various game cues provide players with continuous feedback on how they are doing, and when they make a mistake, they are not excessively penalised, they simply lose a life or start at the last completed level, etc. Feedback is already an important part of education, but specifically, the kind of continuous and rapid feedback used in games has direct pedagogical links to formative assessment in which the learner receives ongoing assessment and feedback that is separated from permanent marks. By removing the fear of grades, learners are encouraged to explore and take risks in their learning without fear of reproach (Heuristics 7, 7.1, 14.3 guideline 3).
4. **Gamified learning should provide activities for learners to engage in.** Gamers are not passive consumers of a game, they are actively engaged in the game; each step and each decision make a difference in the game. Likewise, constructivist principles promote active learning in which the

learner builds their knowledge through mindful activity (Heuristics 13 guidelines-6 and 4, 4.1, 6.2, 7, 7.1, 14.3 guideline-2, 14.4 guideline-1).

5. **Game rules and tutorials need to be explained to players.** All games have an associated set of rules which need to be explained to the players; depending on the complexity of the game, these are also supplemented by hints, tutorials, training missions and guides which help the players advance in the game. In gaming parlance, this is called novice onboarding. Likewise in education, students need to be advised what are the intended learning outcomes and, more specifically for e-learning, to have some training or guidance on how to use the e-learning software (Heuristics 3 guideline-2, 11 guideline-4, 14.2 guideline-1, 14.3 guideline-1).
6. **Gamified learning is a social activity.** Gaming is typically a social activity that revolves around competition or cooperation with other players. Competition often takes the form of challenging, taunting, bragging, etc., and cooperation can take the form of greeting, sharing, helping and gifting, etc. Kim (2011), subdivides gamers into 4 main groups: Killers, Achievers, Explorers and Socializers, and then maps their social actions accordingly. Refer to Figure 22.

Figure 22: Social actions drive social engagement.

Source (Kim 2011, p.119)

A significant subset of the aforementioned social actions should be supported by the e-learning software or the collaborative learning environment. However, considering the pedagogical focus on high-school learning, the negative social actions in the top left quadrant of the graph should be heavily de-emphasised or not supported. This pedagogy supports collaborative and social interaction through the following existing heuristics 9, 11, 11.1, 12.

4.7.8.3 Heuristic 15.2: Build Extrinsic Gamification Elements on top of Existing Learning Processes

Certain gamification elements are not part of established pedagogical approaches; they attempt to leverage people's love of competition and reward to encourage desired learning behaviour. They reflect learner progress and attempt to motivate desired learning behaviour through extrinsic rewards, such as

Points, Leader-boards, Achievements/Badges and Levels. Since these gaming elements are not inherently part of existing pedagogical practices, they need to be built in; however, they should only be used if there is an existing foundation in heuristic 15.1.

Research by (Papastergiou 2009; Deterding et al. 2011; Kim 2011; Muntean 2011; IVETIC & Petrović 2012; Haaranen et al. 2014; Hamari et al. 2014; Iosup & Epema 2014; Morrison & DiSalvo 2014; TechnologyAdvice 2014) is synthesised into gamification guidelines that focus on extrinsic reward; the instructional design of the e-learning software and CLE activities should consider a significant subset of the following guidelines:

1. **Encourage desired learning behaviour with instant reward.** In gamification terms, this is called feedback mechanics and is designed to give an immediate positive feedback (reward) that makes the player feel good about completing something, and motivates them to continue with the desired behaviour. This is achieved by the following mechanisms:
    a. **Points are a quantifiable metric** that track and define progress; they are awarded for undertaking some action or completing some activity. Typical examples include:
        i. **Experience points** are earned directly via the player's actions and are used to track and reward progress or certain activities
        ii. **Redeemable points** are similar to experience points, but can also be *'cashed in'* to purchase virtual or real goods or services.
        iii. **Skill points** are earned by interacting with the game, and reflect mastery of an activity.
        iv. **Social Points** are earned by undertaking socially valuable contributions and actions, and are used to track the social reputation or influence of a player.
    b. **Badges are usually awarded for actions a player has just completed.** Badges offer a more visual display of achievement than points, and can be shown on profile pages or user accounts.
2. **Communicate progress to the learner.**
    a. Learner progress can be reflected to the learner via a combination of gamification mechanisms such as points, badges, a progress bar and levels.
    b. Games are typically segmented into levels of increasing difficulty; likewise, levels can be built into the e-learning software. Their completion marks progress, but also reflects achievement and status.
3. **Provide Social Recognition for desired learning behaviour.** Social recognition can be given to learners by integrating with social media platforms or, in this instance, giving social recognition within the collaborative learning environment (learning community). This can be achieved by showing points, levels and badges on user profiles, or by leaderboards that showcase the most skilled and devoted learners.

4.7.9 Computational Thinking

Building on the review of computational thinking (CT) presented in section 2.4.11, this section further discusses CT research and elaborates on how it is distilled into the e-learning heuristics outlined in Table 22.

ID	Heuristic
6	Support problem-solving through computational thinking.
6.1	Build a foundation for computational thinking.
6.2	Exemplify computational thinking in problem-solving activities.

Table 22: E-learning heuristics based on computational thinking

4.7.9.1 Heuristic 6: Support Problem Solving Through Computational Thinking

Computational thinking is a way of thinking based on computer science concepts with which to reformulate and solve problems. There is currently no authoritative definition of what these computer science thought processes are, but one stable definition involves six concepts: a thought process, abstraction, decomposition, algorithmic design, evaluation, and generalisation. Computational thinking is both an important computer science topic that arguably deserves its own pedagogical heuristics, but also a way of thinking that influences the heuristics for problem-solving. The successful implementation of computational thinking in e-learning software and CLE activities should consider the following sub-heuristics:

- Heuristic 6.1: Build a foundation for computational thinking.
- Heuristic 6.2: Exemplify computational thinking in problem-solving activities.

A wide body of research (Wing 2006b; Wing 2006a; Barr & Stephenson 2011; Wing 2011; Zhou 2011; The Royal Society 2012; Grover & Pea 2013; Curzon et al. 2014; Van Dyne & Braun 2014) theorises that an understanding of computational thinking provides a set of mental tools that can be used in higher-order thinking and problem-solving that extends beyond the computer science domain. This is intuitively understood by computer scientists, and supported by government initiatives. However, as previously noted in section 2.4.11, the empirical evidence to link computational thinking to improved problem-solving, or far transfer to other problem domains, is not conclusive.

4.7.9.2 Heuristic 6.1: Build a Foundation for Computational Thinking

Before students can employ computational thinking, they must first have a clear understanding of what the elements of computational thinking are, be presented with real-world examples to broaden their knowledge base, and become comfortable with the use of computational vocabulary to describe problems and solutions. This acts as scaffolding or pre-training before students start using computational thinking techniques.

Research by (Barr & Stephenson 2011; Lee et al. 2011; Wing 2011; Gouws et al. 2013; Grover & Pea 2013; Selby & Woollard 2013; CAS Barefoot 2014; Curzon et al. 2014) is distilled to the following guidelines that can be used to build a foundation for computational thinking:

1. **Emphasise to students that the focus is not in creating tangible artefacts**, but about fostering specific thought processes.
2. **Provide to students a clear definition of the following computational thinking concepts: abstraction, decomposition, algorithmic design, evaluation, and generalisation**.
3. **Make use of computational vocabulary to describe problems and solutions** to increase the students' comfort with concepts and terminology.
4. **Bring computational thinking concepts to life with the use of real-world examples**.
5. **Make computational thinking more tangible to students by exemplifying it, using algorithms either represented as flowcharts or pseudocode**.

As a sub-heuristic of heuristic 6, heuristic 6.1 shares the same educational benefits and potential challenges as its parent (refer to the previous section).

4.7.9.3 Heuristic 6.2: Exemplify Computational-Thinking in Problem-solving Activities

Once a stable foundation of computational thinking concepts and terminology is established, we must exemplify the ethos, approaches and concepts used in computational thinking through worked examples and problem-solving activities that learners can actively engage in.

Research by (Wing 2006b; Wing 2006a; Barr & Stephenson 2011; Lee et al. 2011; Zhou 2011; Wing 2011; Rick et al. 2012; Gouws et al. 2013; Grover & Pea 2013; Selby & Woollard 2013; Curzon et al. 2014; Lye & Koh 2014; Van Dyne & Braun 2014) is distilled to the following guidelines that can be used to exemplify computational thinking in problem-solving activities:

1. **Use problem-solving activities and worked examples as a vehicle to use and exemplify computational thinking practice**. (Heuristics 4, 4.1)
2. **Make computational thinking processes explicit to learners whilst walking through worked examples and problem-solving activities**. (Heuristic 3)
3. **Use a three-stage progression model: Use-Modify-Create**. Use-Modify-Create is a pattern of engagement that initially scaffolds the learning process and then progressively removes that scaffolding (similar to heuristic 4.1). Initially, students are consumers of someone else's creation, then they modify the model, game or program etc. with increasing sophistication until eventually they have learnt the skills to create entirely new models, games or programs.
4. **Use a problem manipulation environment** for students to engage in computational thinking. A fundamental prerequisite for guideline-3 is the provision of a rich problem manipulation environment in which the learner can be immersed in the Use-Modify-Create approach; the key consideration is to provide learners with several mindful activities in which they can engage. Several example activities are outlined in Vol 2 Appendix E section E.

5. **Instil in learners the ethos behind computational thinking**. As well as a set of concepts that guide thinking processes, computational thinking also has an underlying ethos that is a guide to how to approach a problem. The computational thinking ethos is discussed further in Vol 2 Appendix E section B.4.

As a sub-heuristic of heuristic 6, heuristic 6.2 shares the same educational benefits as its parent (refer to the previous section). In addition, the focus in this heuristic on authentic learning, activities and problem-solving means it offers a positive influence on intrinsic motivation.

4.8 Chapter Summary

This chapter focuses on the synthesis of the e-learning pedagogy; a pedagogy that supports high-school computing with a comprehensive set of heuristics that can be used by teachers or other educators in either the design or evaluation of e-learning software for computer science. The pedagogy considers the following learning theories and other inputs: constructivism, social constructivism, collaborative learning, connectivism, VARK learning styles, ARCS motivational design, cognitive load theory, gamification, and computational thinking. These are then distilled into 21 heuristics and 19 sub-heuristics. The underlying characteristics of the heuristics are that they are:

1. Not intended to instruct good pedagogy to teachers, but
2. Are offered as guidance to teachers and instructional designers in the design or selection of e-learning software appropriate for high-school computer science education;
3. Are not intended to be prescriptive, reductionist or implemented as a mandatory checklist; but
4. Are intended to be used as a toolset in which the correct tools are selected by a teacher or instructional designer based on the specific learning material, intended audience and intended learning objectives; and
5. Although not explicitly considered in this pedagogy, usability is recognised to be critical to e-learning software, and is a mandatory prerequisite.

Considering the substantial number of heuristics and sub-heuristics, and the level of detail associated with each heuristic, the teacher audience is given further support by the provision of summary visual material on how heuristics interrelate, and their potential benefits and dis-benefits. This is facilitated via an:

1. Educational Benefits Matrix,
2. Heuristics Interrelationship Map, and a
3. Heuristics Interrelationship Matrix.

This pedagogy is unique in that it sits at the intersection between pedagogy, e-learning, high-schools, and computer science. It distils an enormous body of pedagogical knowledge into a format accessible to the intended teacher audience, and gives comprehensive coverage to the learning process: to the two processes of external interaction and internal acquisition; and the three dimensions of content, incentive and environment.

5 SYNTHESIS OF THE E-LEARNING EVALUATION PROTOCOL

5.1 Chapter Brief

This chapter focuses on the synthesis of the e-learning evaluation protocol; section 2.3.2 and 2.3.3 outlined the need to focus on pedagogy for e-learning software, and the limitations of existing research. Those research gaps in turn guide the underlying characteristics of the proposed e-learning evaluation protocol. This chapter outlines the origins of the evaluation protocol, and discusses its important characteristics.

5.2 Versions of the E-learning Evaluation Protocol

As discussed in Chapter Three, the e-learning evaluation protocol was iteratively developed and refined through the three phases of this research study; four versions of the e-learning evaluation protocol were developed and released. These are outlined in Table 23.

Phase	Date	Pedagogy
Phase 1	11/05/2015	E-Learning Evaluation Rubric (Pedagogical Coverage.xlsx)
Phase 2-Cycle 2	11/08/2016	E-Learning Software Evaluation Protocol v0.1b
Phase 3	25/06/2017	E-Learning Software Evaluation Protocol (P3) v0.3
Final	09/10/2018	E-Learning Software Evaluation Protocol (Final) v0.4

Table 23: Four versions of the e-learning evaluation protocol

These evaluation protocol releases form the basis of the evaluation results presented in section 6.7.

5.3 Phase 1: The Origins of the E-learning Evaluation Protocol

As discussed in section 3.7.1, during the e-learning design activity (storyboard creation), it became apparent that each e-learning software design / development has a specific pedagogical coverage that needs to be assessed. In response to this need, an initial Phase 1 e-learning evaluation rubric was constructed as follows:

1. Assess as a percentage the e-learning software coverage for each learning objective.
2. Considering that each learning objective is equally weighted, calculate the average learning objective coverage. This becomes the weight factor for the pedagogical coverage.
3. For each educational screen, identify whether it:
    a. Applies a heuristic = 1
    b. Neither applies or violates a heuristic = 0
    c. Violates a heuristic = -1
4. For each heuristic, calculate the percentage of screens that apply the heuristic.

5. Excluding heuristics that cannot be implemented in software, calculate the overall percentage of pedagogical heuristic coverage.
6. The final pedagogical heuristic coverage is weighted based on learning objective coverage, so we multiply learning objective coverage by pedagogical heuristic coverage.

The above rubric and its inherent limitations led to some important areas of consideration that are reported in the results section 6.7.1, and were used to set the direction for the research into e-learning evaluation protocols. Based on this relatively uninformed start, this study iteratively developed an e-learning evaluation protocol designed with the characteristics discussed in the remainder of this chapter.

5.4 Characteristics of the E-learning Evaluation Protocol

Building on the academic foundations of section 2.3.3, the e-learning evaluation protocol presented in this thesis, is characterised by:

1. Support for both formative and summative evaluations;
2. A focus on pedagogical quality rather than usability issues;
3. Support for the evaluation of learning objectives as well as pedagogical quality;
4. Consideration of the educational setting in which the e-learning software will be used;
5. The definition of a robust protocol for evaluation steps based on existing best practice in evaluation (including guidelines on the number and experience of evaluators);
6. The definition of detailed design and evaluation criteria to give evaluators a clear basis for evaluation;
7. The provision of quantifiable results that can be used for comparative evaluations; and
8. A focus on the reliability and validity of evaluation results.

5.4.1 Intended Usage

As is the norm, the pedagogical heuristics and criteria defined in this research are dual purpose: to guide the pedagogical design of e-learning software, and to serve as the basis of a protocol to guide evaluation activities (Ardito et al. 2006; Masip et al. 2011). When used for assessment purposes, the evaluation protocol can be used both for formative and summative assessments. Considering the context of this research and its focus on high-school computing, it is envisaged that school teachers will typically use it in three scenarios (formative evaluation, summative evaluation, and comparative evaluation); these are visually represented in Figure 23.

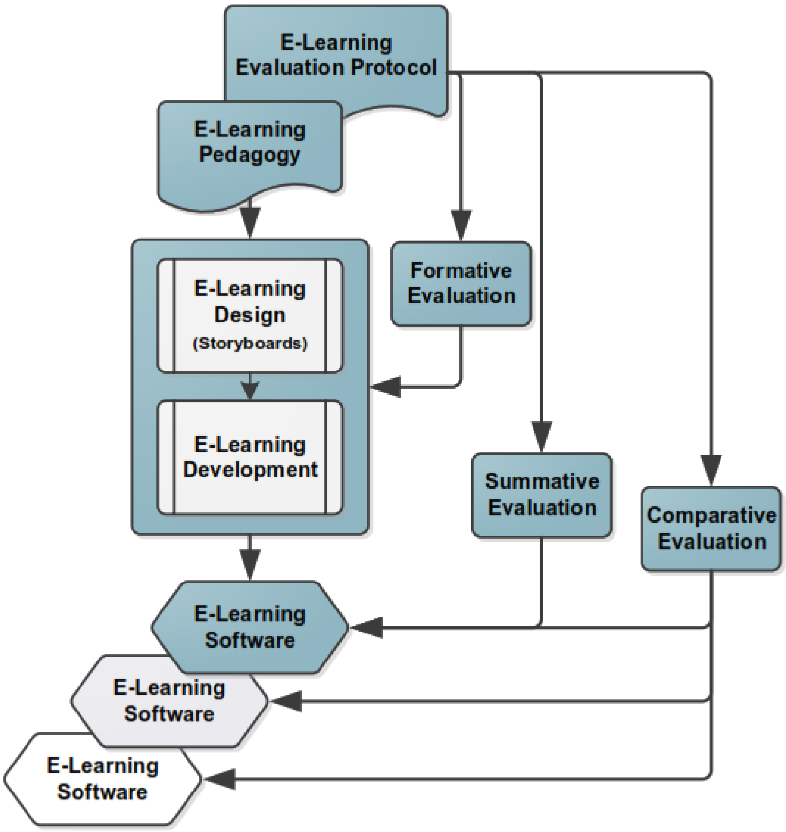


Figure 23: Intended usage of pedagogical heuristics and evaluation protocol

The formative evaluation of e-learning software occurs during the design and development stages to improve the educational value of the software before it is released. During the design and development process, after the storyboard design is stable, a different set of (impartial) teachers or instructional designers can use the evaluation protocol to give a formative evaluation. The formative evaluation can focus either on a detailed storyboard design or a pre-release version of the software. In this manner, the evaluation group can iteratively feed into the design and development process to improve the educational value of the software.

The evaluation of e-learning software prior to its use is employed so that teachers can make the right software selection, and decide which e-learning resources best fit with the pedagogical strategies intended for use in their classroom. Squires and Preece concur that: *"Using educational software requires teachers to decide which software to use with their students, for what purpose and in what situations, i.e. to conduct predictive evaluations of the use of educational software. Informal predictive evaluations rely on past personal experience to make value judgements about the quality and potential use of an educational software application before using it in the classroom."* (1999, p.467)

The systematic comparative evaluation of an e-learning software with one or more different implementations of equivalent software comes last. In this scenario, the evaluation protocol is used to inform selection decisions for e-learning software that are intended to support long-term curriculum and teaching needs (Squires & Preece 1996; Squires & Preece 1999; Çelik 2012). Reeves (1994) reinforces this point by asserting that summative assessments are particularly important for the comparative evaluation of different e-learning implementations that focus on the same learning objectives. He states that, *"it is* *imperative that criteria for evaluating various forms of CBE be developed that will result in more valid and useful evaluations"* (1994, p.222).

5.4.2 Focus on Overall Pedagogical Quality, not on Individual Usability Issues

The history of heuristic evaluations is based on identifying usability problems. The focus is almost exclusively on the negative process of finding and classifying the severity of usability issues. This is reflected in the work of Nielsen and Molich (1990), Nielsen (1994), Dringus (1995), Squires and Preece (1996), Parlangeli et al. (1999), Squires and Preece (1999), Reeves et al. (2002), Law and Hvannberg (2004), Dringus & Cohen (2005), Ardito and Costabile (2006), Lanzilotti and Ardito (2006), Masip et al. (2011), Inostroza and Rusu (2012) and Zaharias and Koutsabasis (2012).

This evaluation protocol has its basis in heuristic evaluations, but in contrast measures overall support, be that negative (identifying pedagogical issues) or positive (identifying areas of pedagogical strength). This has a more conceptual alignment with the work of Shee and Wang (2008), who studied e-learning evaluations based on positive ratings and rank comparisons, and the work of Abderrahim et al. (2013), whose evaluations were based on positive ratings.

Furthermore, building on the literature review in section 2.3.3, this e-learning evaluation protocol proposes that a foundation of usability must already exist to resolve potential technical and graphical issues. Meaning a separate usability evaluation is strongly recommended. This frees this evaluation protocol to focus more specifically on educational content and instructional design (pedagogy).

5.4.3 Evaluate Content Quality as well as Pedagogical Quality

This evaluation protocol gives focus to the pedagogical quality of e-learning software. However, it is important to note that even if a specific e-learning implementation is pedagogically excellent, it still may not lead to the desired learning outcomes if the educational content is not appropriate. As such, in alignment with the observations of Squires and Preece (1999) , this evaluation protocol is one of the few that explicitly measures content quality and the e-learning software's support of intended learning objectives (curriculum). This evaluation protocol therefore focuses on educational value, which is the combination of content quality and pedagogical quality. This relationship is reflected in Figure 24.

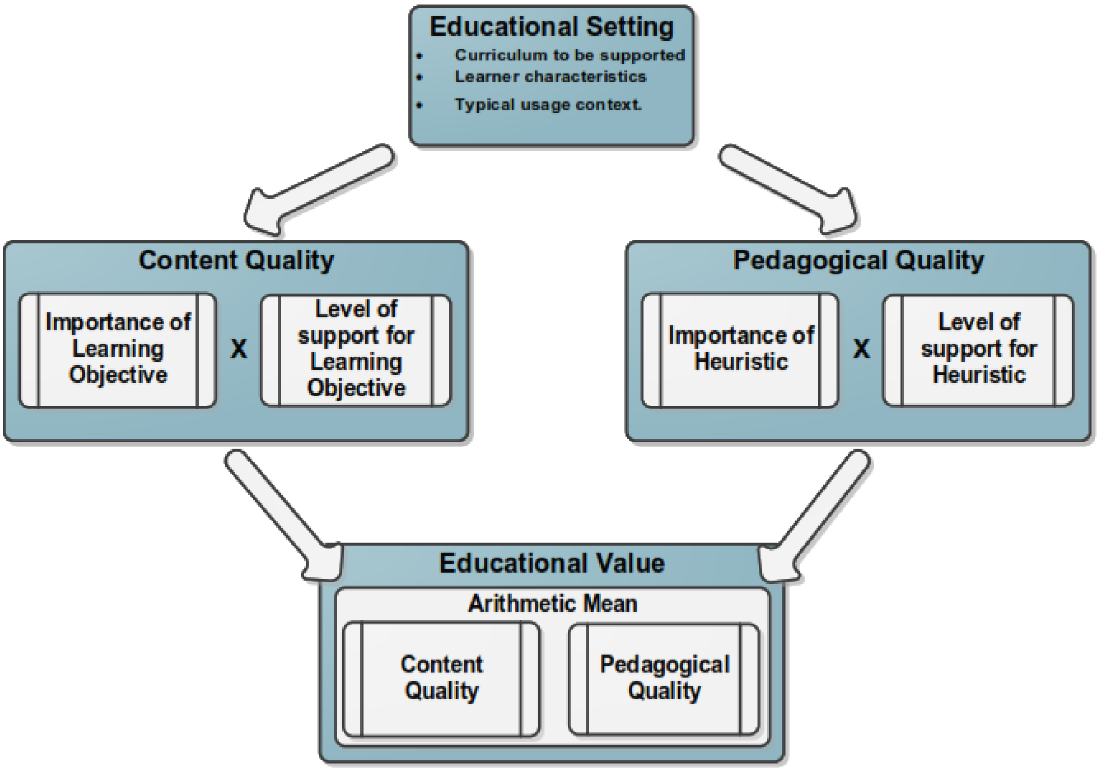


Figure 24: The composition of Educational Value

5.4.4 Not all Heuristics or Learning Objectives are Applicable or are of Equal Importance

The evaluation of any e-learning software cannot be held in isolation; there must first be consideration of the educational setting (learning context) in which the software will be used. An important characteristic of this evaluation protocol is that it explicitly considers the intended learning context, such as the target audience and their characteristics, and the typical context for using the e-learning software. Squires and Preece emphasise *that "the use of educational software is context dependent. It is not possible to evaluate an educational software application predictively without reference to a perceived educational setting"* (1996, p.19).

If teachers are undertaking evaluations for themselves, they will typically already know this information. If the evaluation is requested by an educational institution, then they may give this information to the evaluation group, or potentially there may be some interchange between those who have requested the evaluation and the evaluation group in order to finalise the educational setting.

The educational setting is particularly important since it guides evaluators in defining whether specific learning objectives and heuristics are applicable within the given learning context. The adaptability of e-learning heuristic evaluations is encouraged by Squires and Preece (1999), Dringus and Cohen (2005) and Inostroza and Rusu (2012). Dringus and Cohen advise *"the need for instructors to carefully select their own heuristic items"* (2005, p.3).

It follows that if a learning objective or heuristic is judged applicable, then the evaluator assesses its relative importance in the given learning context. This increases the accuracy and validity of the evaluation since it eliminates noise (non-applicable learning objectives and heuristics), and gives a weighted focus on the remaining learning objectives and heuristics.

5.4.5 Number of Evaluators

One shortcoming of heuristic evaluations is the potential for subjectivity since the evaluation (although guided) is ultimately based on the evaluator’s judgement, experience and disposition at the time of the evaluation. As well as potential subjectivity, this can also lead to incomplete evaluation coverage, in which an evaluator overlooks pedagogical issues or strengths. Based on six previous research studies, Nielsen (1994) contends that a single evaluator typically identifies only 35% of usability problems in an interface. Arguably, these concerns are further compounded by the ethereal nature of teaching and learning.

Based on the work of Nielsen and Molich (1990) and Nielsen (1994), the widely accepted approach to mitigate this risk is to employ multiple evaluators who work individually, to avoid bias, and then aggregate their findings. They offer evidence that there is considerable non-overlap between the sets of usability problems found by different evaluators, and that significantly better performance is possible by aggregating the evaluations from several evaluators. However, they conclude that beyond a certain point, there are diminishing returns from adding evaluators. The final recommendation is to use between three to five evaluators. This approach has become a de facto standard, and has been used in a large number of studies (Dringus 1995; Parlangeli et al. 1999; Squires & Preece 1999; Reeves et al. 2002; Lanzilotti & Ardito 2006; Alsumait & Al-Osaimi 2010; Inostroza & Rusu 2012; Zaharias & Koutsabasis 2012).

5.4.6 Experience of Evaluators

The evaluation protocol is intended for use by teachers or other education specialists in the *‘expert’* evaluation of e-learning software; however, the term expert does not necessarily mean an expert in the evaluation process.

There is evidence to suggest that there can be a significant performance differential between evaluators, even those with broadly the same background and qualifications. However, we cannot conclude that supposed *‘good’* evaluators will consistently perform better. Nielsen and Molich (1990) identify that *‘good’* evaluators will not necessarily find all the easy problems found by *‘poor’* evaluators, and then go on to identify hard problems. In fact, poor evaluators often find hard problems, and good evaluators can overlook easy problems. Nielsen (1994) elaborates that although there is a better than random consistency in the evaluators' ability to find usability problems across multiple evaluations, there remains a significant unexplained performance variance from one evaluation to the next. It is postulated that it might be possible to identify a group of good evaluators based on historical performance. However, it is likely to be a slow process which would sacrifice performance in early evaluations. This analysis of evaluator performance is the basis of why multiple evaluators are highly recommended for an e-learning evaluation. In addition, instead of trying to find expert evaluators, it is more productive to focus on the level and area of expertise of the evaluator. Citing his research from 1992, Nielsen (1994) discusses the conceptual grouping of evaluators as novices, single experts and double experts.

In the context of this research, a novice has general knowledge and expertise in using computers, a single expert has knowledge and expertise in teaching and pedagogy, and a double expert additionally has knowledge and expertise in the domain of computer science. The evaluation protocol is prescribed to the level of detail that a novice could undertake an e-learning evaluation. However, according to Nielsen (1994), a single expert is 1.8 times as good as a novice, and a double expert is 2.7 times as good (identifying 60% of usability issues). These findings do not directly transfer to this research since our focus is not on usability issues, but on educational value. However, it does give a good indicator of the potential value of having double experts. It should also be noted that to conduct a full e-learning evaluation of educational value (content quality and pedagogical quality) the evaluator must be a double expert since only someone with computer science expertise can evaluate content quality. What exactly constitutes knowledge and expertise in a given area is difficult to determine, but it is postulated to be: a relevant academic qualification and a minimum of one year, or preferably two years, of experience. If the evaluator does not have a relevant qualification, then their experience should be significantly longer. For improved clarity to the intended teacher audience, in the final version of e-learning evaluation protocol the terminology used to describe evaluator experience of novice, single expert and double expert was replaced with novice, experienced and expert.

5.4.7 Protocol Steps for E-learning Evaluation

To ensure reliability and build towards the validity of the e-learning evaluation; individual evaluators and different evaluation groups must approach the evaluation in a consistent manner. Hence, a set of detailed guidance steps for e-learning evaluations is prescribed. This is documented in detail in Vol 3 Appendix N section 4.

One area of importance for the e-learning evaluation protocol is its appropriateness for the intended teacher audience; this is discussed in sections 6.7 and 7.9. However, it must be noted there is a tension between specifying a rigorous set of guidance steps for e-learning evaluations and whether that evaluation process will ultimately be accessible and usable for the teacher audience.

Innovation is pursued in the e-learning evaluation protocol through: the underlying heuristics, the evaluation coverage of both pedagogy and subject content (Squires & Preece 1999), the focus on quantifiable metrics, and a focus on heuristic support rather than only heuristic violations. However, considering the dictionary definition of protocol as "*a detailed plan of a scientific or medical experiment, treatment, or procedure"* (Merriam-Webster 2016), it is purposely decided that the protocol steps (i.e. the evaluation procedure) should be as standard as possible. The protocol steps are based on the stability of existing academic research, so as to avoid the possibility that they in some way corrupt the evaluation results. The evaluators should follow a common, simple protocol for conducting their evaluation (Zaharias & Koutsabasis 2012); this in turn supports research reliability and validity.

The protocol steps for carrying out the evaluation have their popular origins in the work of Nielsen (1994), and have remained comparatively stable, as reflected in studies using very similar variations of the same protocol. Such studies include, but are not limited to: Dringus (1995), Parlangeli et al. (1999), Reeves et al. (2002), Ardito and Costabile (2006), Lanzilotti and Ardito (2006), Masip et al. (2011), Inostroza and Rusu (2012) and Zaharias and Koutsabasis (2012). The protocol steps used in this study follow a similar vein and, in particular, pay reference to Reeves et al. (2002). At a high-level, the e-learning evaluation protocol follows a predefined process which is broken into three broad stages: Preparation, Individual Evaluations and Building Consensus. Please refer to Figure 25 for a visual representation of the evaluation process.

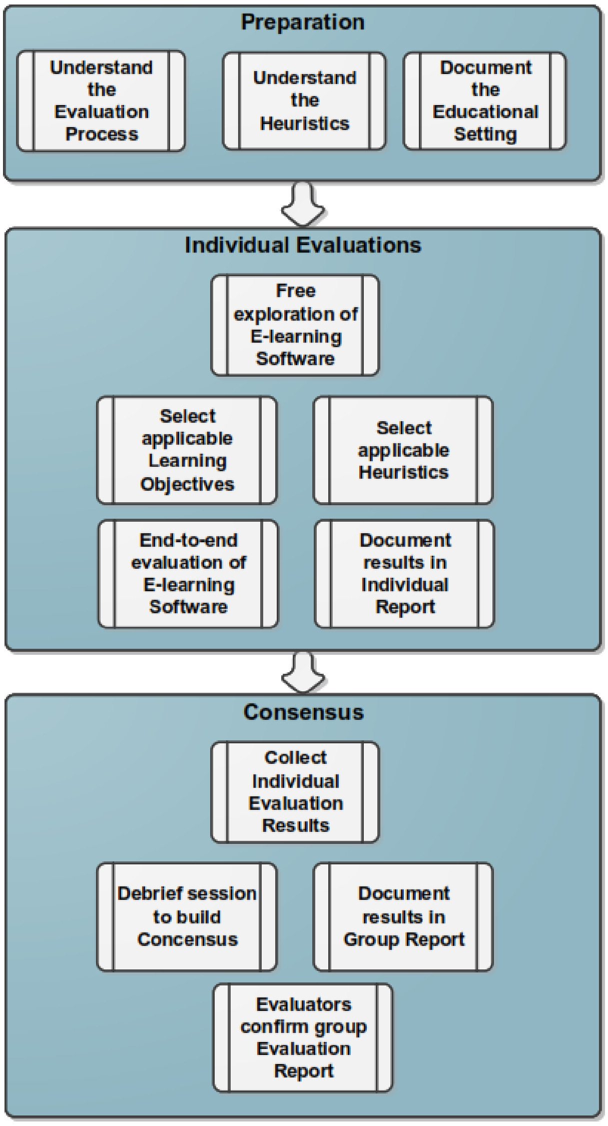


Figure 25: High-level flow of e-learning evaluation

5.4.7.1 Preparation

The exact form and level of attention given to the preparatory stage are highly dependent on whether:

1. The evaluators are novices, single experts or double experts;
2. Whether the evaluators have previous knowledge of the heuristics;

3. Whether the evaluators have previously undertaken a similar evaluation, and therefore have knowledge of the evaluation protocol; and
4. Whether the evaluators are documenting the educational setting or are being given the educational setting by the evaluation requestor.

The preparatory phase is used to provide the evaluators with the structure and guidance needed to undertake a reliable and valid evaluation. Typically, information (pre-reading) and/or training is provided for: the evaluation process; the evaluation heuristics; domain-specific content and curriculum; and, potentially, the educational context in which the e-learning software will be used. In some studies, the evaluators are then given the opportunity to customise the evaluation heuristics according to this information / training.

5.4.7.2 Individual Evaluations

Each evaluator conducts his or her evaluation individually and independently to form an unbiased opinion. Typically, evaluators use a minimum of two iterations through the e-learning software; a free exploration is used to get familiar with the flow of the software, its basic functions, and to form a general view of the software's design ethos.

Subsequent iterations are used to identify findings in relation to content and pedagogical quality. As discussed previously, the proposed heuristics are not intended to be implemented as a mandatory checklist, but as a toolset in which the correct tools (heuristics) are selected by a teacher or instructional designer based on the educational setting. It is therefore critical that the evaluators consider the educational setting in which the software will be used when deciding whether specific heuristics and learning objectives are applicable, and if applicable, their importance and level of support within the software. Each evaluator documents their findings in parallel in a structured evaluation report, which includes descriptive comments and quantitative evaluation metrics.

5.4.7.3 Building Consensus

The final objective of the evaluation process is a single evaluation report that fairly represents the aggregated findings of the set of evaluators. In support of this objective, a debrief session is run by an unbiased facilitator whose role is to encourage effective discussion, align the individual evaluation findings, and aggregate them into a consolidated response, which should be representative of the group.

The consolidated response is documented by the facilitator in a final report, which is then shared with the evaluators, either for their feedback or confirmation that it is accurate.

5.4.8 The Need for Quantifiable Evaluation

It is typical during usability evaluations to assess the severity of each usability issue. According to Nielsen (1994) this: ensures that appropriate resources are used to fix the most serious problems; helps to ascertain whether additional usability efforts are necessary; and supports the decision-making process on whether a software can be released to the intended audience. The assignment of such severity levels requires the use of quantifiable metrics. In the context of this research, the assignment of quantifiable metrics is necessary for the previous reasons, but it is all the more important since we are not evaluating the severity of individual usability issues, but instead administering a ground-up evaluation of the educational value of the entire e-learning software. Reeves (1994) cites Scriven (1993) in asserting that there is an almost universal need to do comparative evaluations. He argues that criteria for evaluating various forms of Computer-Based Education must be developed to ensure more valid and useful evaluations. Reeves concludes that *"there is certainly merit and utility in eventually grounding the ratings in quantitative values"* (1994, p.241). The underlying focus on quantifiable learning evaluation metrics that enable selection and comparative evaluations is also proposed by the lesser known work of Abderrahim et al. (2013).

This evaluation protocol proposes to ground the e-learning evaluation in quantitative values by evaluating educational value in terms of content quality (the level of support for the given learning objectives) and pedagogical quality (the level of support for the pedagogical heuristics relevant to the learning context).

As already discussed, the importance of each learning objective and each heuristic is specified by the evaluator after consideration of the learning context (educational setting). The importance value is then used as a weight factor in calculating the maximum support and the weighted support.

The support the e-learning software provides to each learning objective and each heuristic is also specified by the evaluator. Both the importance and support values are then used to calculate the following:

- Weighted Support for Learning Objectives (refer to Equation 1)
- Maximum Support for Learning Objectives (refer to Equation 2)
- Percentage Support for Learning Objectives (refer to Equation 3)
- Weighted Support for Pedagogical Heuristics (refer to Equation 4)
- Maximum Support for Pedagogical Heuristics (refer to Equation 5)
- Percentage Support for Pedagogical Heuristics (refer to Equation 6)
- Percentage Educational Value (refer to Equation 7)

n = Number of Learning Objectives

m = Number of Pedagogical Heuristics

$$\sum_{i=1}^{n} Importance\ of\ Learning\ \text{Objective}\ x\ Support\ for\ Learning\ \text{Objective}$$

Equation 1: Weighted support for learning objectives

$$\sum_{i=1}^{n} Importance\ of\ Learning\ \text{Objective}\ x\ Maximum\ Support$$

Equation 2: Maximum support for learning objectives

$$\frac{Weighted\ Support\ for\ Learning\ \text{Objectives}}{Maximum\ Support\ for\ Learning\ \text{Objectives}}\ x\ 100$$

Equation 3: Percentage support for learning objectives

$$\sum_{i=1}^{m} Importance\ of\ Pedagogical\ Heuristics\ x\ Support\ for\ Pedagogical\ Heuristics$$

Equation 4: Weighted support for pedagogical heuristics

$$\sum_{i=1}^{m} Importance\ of\ Pedagogical\ Heuristics\ x\ Maximum\ Support$$

Equation 5: Maximum support for pedagogical heuristics

$$\frac{Weighted\ Support\ for\ Pedagogical\ Heuristics}{Maximum\ Support\ for\ Pedagogical\ Heuristics}\ x\ 100$$

Equation 6: Percentage support for pedagogical heuristics

$$\frac{\%Support\ for\ Learning\ \text{Objectives}\ +\ \%Support\ for\ Pedagogical\ Heuristics}{2}$$

Equation 7: Percentage educational value

5.4.8.1 Scale Format

As discussed in the previous section, a key objective of the e-learning evaluation protocol is to provide quantitative metrics by which to assess the educational value of e-learning software. With this in mind, the response scales and associated scale labels used in the evaluation protocol are of particular importance in securing quantitative responses that are reliable and valid. Unfortunately, the definition of appropriate response scales and scale labels are not simple tasks since the academic debate in these areas span over a century, numerous academics, and many competing findings. Cox (1980) offers an indicative literature review of research from 1915 onwards that spans over 40 authors. It touches upon areas such as: scales of value methods vs unstructured responses, the number of response alternatives, reliability, validity, response times, respondent preference, inclusion of an uncertain category, information on theoretic measures, interpretability of descriptive statistics, and statistical efficacy of sample estimates. However, the areas which are most vigorously debated are the optimal number of response alternatives, whether that number is content-specific, and what impact, if any, it has on reliability and validity. Cox's contention that there is a lack of consensus in these areas is also shared by Matell and Jacoby (1971), Preston and Colman (2000), Darbyshire and McDonald (2004), Weijters et al. (2010), and other researchers.

The scope of this research is not to become embroiled in this debate but to focus on defining an equitable set of response scales and scale labels to ensure reliability and validity. To achieve this objective, the following has been considered.

5.4.8.1.1 There is No Optimal Number of Response Alternatives for all Circumstances

According to Cox (1980, p.407), *"If the number of response alternatives were to be established democratically, seven would probably be selected (Symonds 1924; Morrison 1972; Ramsey 1973); seven is the modal number of response alternatives for the scales reviewed by Peter (1979)."* Also, citing a number of authors, Preston and Colman (2000) concur, that in current practice, most rating scales contain either five or seven response alternatives. However, other researchers propose as few as two or three alternatives, and others suggest over 20 can be used. Matell and Jacoby (1971), cite Champney and Marshall (1939) in their assertion that, under favourable rating conditions, scales with five to seven points may offer inexcusably inaccurate results, and that under the right conditions a scale of 18 to 24 points may be appropriate.

Conklin (1923), Wittink and Bayer (1994), Myers (2000), and Preston and Colman (2000) all advocate greater than seven response alternatives, with Preston and Colman concluding that *“rating scales with 7, 9, or 10 response categories are generally to be preferred”* (2000, p.10).

The key consideration is that the response scale should be refined enough for the respondent to be able to transmit the necessary information, but not so refined that it encourages response error. Following this rationale, Cox (1980), Garland (1991), Darbyshire and McDonald (2004), Preston and Colman (2000) , and Weijters et al. (2010) concur that there is no optimal number of response alternatives, and that it is dependent on the context and the purpose of the scale. However, Cox (1980) does offer some recommendations: that two or three alternatives are inadequate since the alternatives cannot transmit enough information; and that offering beyond nine alternatives will likely yield marginal returns in improving the survey instrument. Finally, it is asserted that in a balanced scale an odd number of response alternatives is preferable if the respondent can justifiably take a neutral stance. These guidelines are echoed by Darbyshire and McDonald (2004, p.17) who conclude that *“longer, balanced and unlabelled scales offer the maximum flexibility and reliability in the majority of cases”.*

5.4.8.1.2 Reliability and Validity

The impact of scale format on reliability is another area of contention amongst academics; Symonds (1924) contends that deciding the number of response alternatives of a scale is primarily one of reliability, and claims that optimal reliability is found in a 7-point scale. Other academics offer alternate suggestions to maintain optimal reliability: Champney and Marshal (1939) suggest a 9-point scale; Wittink and Bayer (1994) suggest a 10-point scale; whereas Jahoda et al. (1951) and Ferguson (1941) assert that scale reliability increases, within limits, as the number of response alternatives increases. In stark contrast, Bendig (1954) and Komorita (1963) advise that instrument reliability is independent of the number of response alternatives. In addition, Cronbach (1950) cautions that to increase the reliability of an instrument is meritless unless validity is increased proportionally.

In consideration of instrument validity, Preston and Colman (2000) report that there are comparatively few studies in which validity is a criteria to evaluate the optimal numbers of response alternatives. Again, the findings are mixed. Matell and Jacoby (1971) conclude that both reliability and validity are independent of the number of response alternatives and that, in practice, longer scales can be collapsed to as few as two or three response alternatives. In contrast, Loken et al. (1987) found that 11-point scales offer superior validity compared to 3- or 4-point scales. Furthermore, Hancock and Klockars (1991) surmise that the scores from 9-point scales correlate better than 5-point scales against objective measures of the original stimuli.

In the face of such mixed findings, this research aligns with previous studies that assert that longer scales support increased reliability and validity, and in particular draws upon the findings of Preston and Colman (2000). Preston and Colman conclude that *"The most reliable scores were those from scales with between 7 and 10 response categories, the most valid and discriminating were from those with six or more response categories or – in the case of intertertile discriminating power – those with nine or more"* (2000, p.10). Furthermore, that respondents prefer scales with 10, 9, or 7 response alternatives.

5.4.8.1.3 Interval Response Scale and Scale Labels

A further consideration in defining a scale is what type of data that scale can collect, and therefore whether the scale supports the analysis techniques required by the research. There is wide academic debate on whether Likert scales are ordinal or interval in nature. However, it is widely accepted that interval data offers a higher level of measurement precision, and supports a superior set of statistical operations (Field & Hole 2003; Lazar et al. 2010; Pallant 2001; Field 2013). Darbyshire and McDonald (2004) acknowledge this concern, and suggest that where a more sophisticated statistical analysis is needed that a numeric scale is more suitable since a labelled scale is more prone to be interpreted as ordinal data. Furthermore, labelled scales offer an increased challenge for larger scales in defining meaningful labels for each point that can be perceived as equidistant (Myers 2000). This can in turn lead to different interpretations of what the labels mean and therefore reduce reliability. However, it is also argued that labelled scales reduce ambiguity regarding the meaning of each point on the scale and therefore can increase the level of reliability in comparison to numeric scales (Bradlow & Fitzsimons 2001). Considering all these points, Darbyshire and McDonald recommend anchoring *"numeric scales with terms which are specific enough to convey the meaning of the scale to the respondent"* (2004, p.25).

5.4.8.1.4 Respondent Preference

According to Preston and Colman (2000), respondent preference on scale format has not been investigated in depth in previous studies. In their study, Preston and Colman measure respondent preference for scales with 2 to 11 response alternatives and 101 response alternatives. Respondent preferences were measured according to the dimensions of ease of use, speed of use, and the expressiveness of the scales. They offered statistically significant results indicating that short and very long response scales have the lowest overall ratings, whilst the best overall preference rating was for the ten-point scale, closely followed by the seven-point and nine-point scales. Building on these findings, and in alignment with Jones (1968), a graphical scale is also considered to further improve the perceived accuracy, reliability, interest and, most importantly, to reduce potential ambiguity.

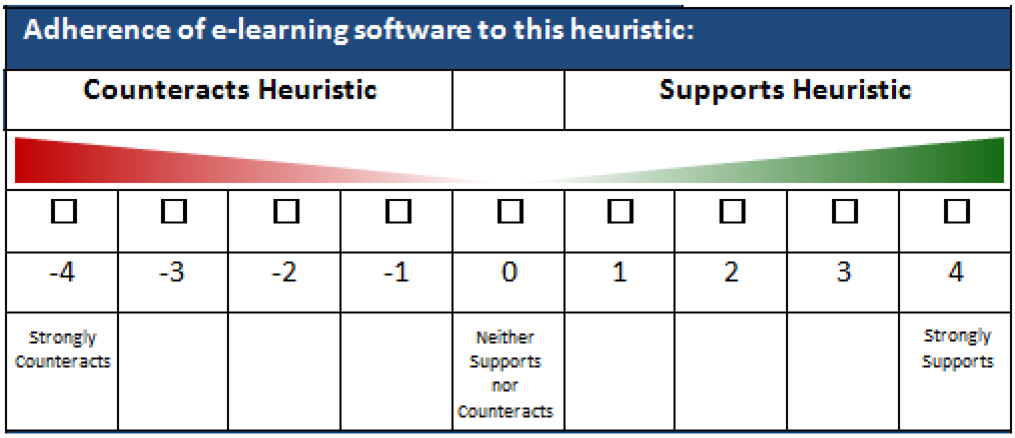
5.4.8.1.5 Design of Response Scale

5.4.8.1.5.1 Support for Learning Objectives and Heuristics

Based on the guidelines discussed in section 5.4.8.1 and its sub-sections, and in conjunction with the purpose of the scale to quantitatively measure an e-learning software's support of each learning objective and each heuristic, it is decided that:

1. A numeric scale is used since this most aligns with interval data.
2. A balance scale is used since an e-learning software may counteract or support each heuristic.
3. An odd scale is used since an e-learning software may justifiably offer neutral support to a heuristic.
4. Based on points 1 to 3, a nine-point scale is chosen, which is accordingly viewed to support both reliability and validity.
5. A nine-point scale is chosen since it allows four response alternatives on each side, which gives good granularity in measuring the level of support or counter-support an e-learning software has for a heuristic.
6. To remove ambiguity, labels are used on the extreme and middle scale points.
7. To further remove ambiguity, two sliders are graphically represented under the numeric response alternatives.

Considering the previous points, the resulting response scale is presented in Figure 26.



Adherence of e-learning software to this heuristic:								
Counteracts Heuristic					Supports Heuristic			
☐	☐	☐	☐	☐	☐	☐	☐	☐
-4	-3	-2	-1	0	1	2	3	4
Strongly Counteracts				Neither Supports nor Counteracts				Strongly Supports

Figure 26: Response scale for adherence of e-learning software to this heuristic.

5.4.8.1.5.2 Importance of Learning Objectives and Heuristics

Similarly, the following decisions were made in the design of the response scale for measuring the Importance of Learning Objectives and Heuristics.

1. A numeric scale is used since this most aligns with interval data.
2. A unidirectional scale is used since the importance of a learning objective or heuristic is a positive attribute. However, it can be decided that a learning objective or heuristic is Not Applicable for a specific learning context or e-learning software.
3. To remove ambiguity, labels are used as anchors on the extreme points.
4. A five-point scale is chosen since it allows a Not Applicable option as well as 4 support options, which gives good granularity in measuring the level of support.

Considering the previous points, the resulting response scale is presented in Figure 27.

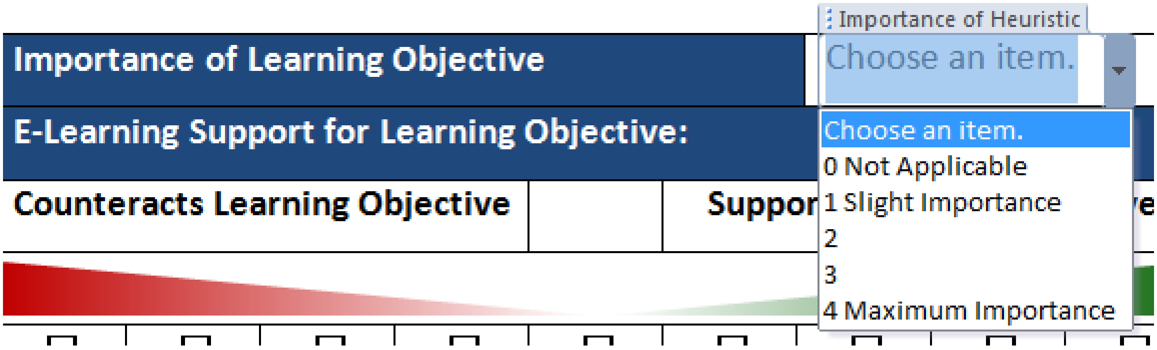


Figure 27: Response scale for level of importance.

When reviewing the response scale prior to the Phase 3 workshop, the researcher recognised that having three anchor points on a five-point scale was counterintuitive and since the five-point scale is reasonably short, decided to use the following labelled response scale to denote level of importance of both learning objectives and heuristics (refer to Figure 28).

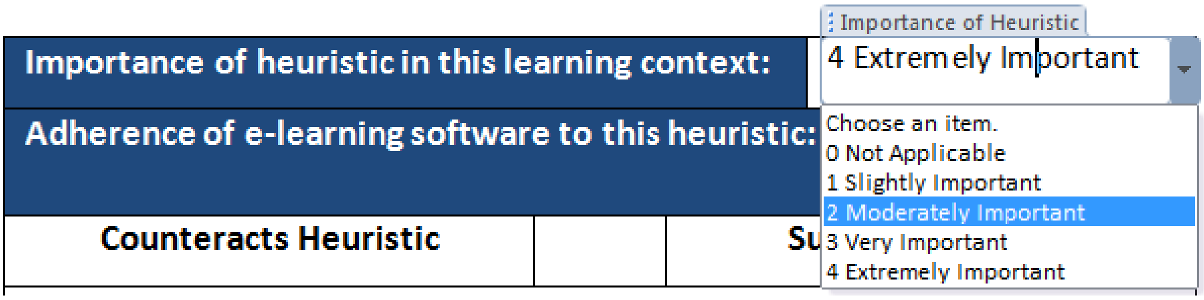


Figure 28: Adjusted response scale for level of importance.

5.4.9 Uniqueness of the E-learning Evaluation Protocol

As reflected in the work of Lanzilotti and Ardito (2006), Alsumait and Al-Osaimi (2010), Masip et al. (2011), Inostroza and Rusu 2012 (2012) and Zaharias and Koutsabasis (2012), a standard approach to ascertain the performance and validity of an evaluation protocol is to conduct a comparative evaluation of the same software using an established evaluation protocol with the new protocol.

However, in consideration of the extensive literature review carried out in this study, and with reference to characteristics of the e-learning evaluation protocol discussed in the previous sub-sections, there does not seem to be an equivalent established e-learning evaluation protocol that is: specified at this level of detail; that focuses on pedagogy instead of usability; that evaluates subject content to give an overall focus on education value; and that measures adherence (positive and negative) instead of identifying issues and severity levels.

This poses a challenge in establishing the performance and validity of the e-learning evaluation protocol via a direct comparison with another evaluation protocol; however, ultimately, it is a positive indicator of the uniqueness of this e-learning evaluation protocol.

5.5 Chapter Summary

This chapter focuses on the synthesis of the e-learning evaluation protocol; it outlines the rudimentary beginnings of the original evaluation rubric in Phase 1. More importantly, it discusses in detail the characteristics of the evaluation protocol that make the fourth version (refer to Vol 3 Appendix N) of the protocol novel and arguably unique. The e-learning evaluation protocol is characterised by:

1. An intended audience of high-school teachers, or education experts typically in the field of instructional design;
2. Support for formative, summative, and comparative evaluations;
3. A focus on pedagogical quality rather than usability issues;
4. Support for the holistic evaluation of educational value, which considers both learning objectives as well as pedagogical quality;
5. Consideration of the educational setting in which the e-learning software will be used, and explicit consideration that not all heuristics or learning objectives may be applicable in that educational setting;
6. The definition of a robust protocol for evaluation steps, based on existing best practice in evaluation (including guidelines on the number and experience of evaluators);
7. The definition of detailed design and evaluation criteria to give evaluators a clear basis for evaluation.
8. The provision of quantifiable results that can be used for comparative evaluations; and
9. A focus on the reliability and validity of evaluation results.

The importance of points 8 and 9 in defining quantifiable results that are valid and reliable means the scale format of the evaluation protocol is discussed at length, giving the rationale for the design of the response scales for both adherence and importance of heuristics and learning objectives.

6 IMPLEMENTATION AND RESULTS

6.1 Chapter Brief

This chapter presents the results from all phases and all research elements within the study. The results are typically presented thematically, and where it adds value within a theme, according to the phases. Specifically, this chapter presents:

1. The research instruments and materials, used as the basis to collect research results;
2. The Phase 1 pilot findings, and how they affected the remaining study and its direction;
3. The teacher and education expert feedback on the e-learning pedagogy;
4. Exploratory findings from student usage of the e-learning software prototype during Phase 1 and 2;
5. Phase 3 results;
6. The e-learning evaluation protocol results.

On consideration that this research is based on a mixed methods exploratory design, there is a qualitative priority in the early exploratory phases. However, due to the significant volume of research findings and results, the thick first-person literary description customary in qualitative research is avoided. With respect to brevity, the results for points 2, 3 and 5 above are presented in an abridged form in this chapter. However, they reference detailed appendices in which the exploratory findings are presented with a richer text description and the voice of the participants is carried through in the use of direct quotes. The results for Phase 3 (Point 4) are primarily quantitative, and are presented fully in this chapter. The results from this chapter are then pulled together and interpreted in a cohesive discussion in Chapter Seven.

6.2 Research Instruments and Materials

Building on Chapter 3, this section outlines the instruments (measurement devices) and supporting materials used in performing this research study.

6.2.1 Pedagogy Evaluation Feedback Document

A central component of this research was the involvement of teachers and education experts in the evaluation and feedback of the e-learning pedagogy. In the Phase 1 Pilot, this was guided more informally by several high-level questions (refer to section 3.4.4.2).

To ensure greater consistency between evaluations and evaluators, from Phase2-Cycle1 onwards, a Pedagogy Evaluation Feedback document was introduced. This document incorporated similar questions to those in Phase 1, via a combination of Likert and open questions. The Likert scale ranged across: Strongly Disagree, Disagree, Neither Agree nor Disagree, Agree and Strongly Agree. For reference, a completed Pedagogy Evaluation Feedback document is included in Vol 3 Appendix G.

Based on the findings from Phase2-Cycle1, this document was updated to include further questions and was used in Phase2-Cycle2 and in Phase 3. For reference, the updated (and completed) Pedagogy Evaluation Feedback document is included in Vol 3 Appendix F.

6.2.2 E-learning Software Prototype

Building on section 3.2.6, as a proof of concept, prototype e-learning software was developed according to the pedagogical heuristics outlined in the e-learning pedagogy document. An incremental and iterative development methodology was used to deliver updated versions of the e-learning software prototype for each phase/cycle.

6.2.2.1 Phase 1

In Phase 1, a single e-learning software prototype was developed with a focus on algorithms (Algorithms V04a). This was hosted on a SCORM cloud platform called SCORMCloud, which in turn linked to a collaborative learning environment called TEAMIE.

6.2.2.2 Phase 2 - Cycle 1

The prototype e-learning software developed in Phase 1 was revised in accordance with the research findings from the Phase 1 study and the updated pedagogical heuristics resulting from Phase 1. The new version of the software (Algorithms V08a) was also expanded to include learning content on computational thinking.

In Phase2–Cycle1, the TEAMIE collaborative learning environment was replaced by Google Apps for Education. This decision was taken since Google Apps provides additional functionality, is free for Schools, and is provided by a well-known brand with a large market presence and support infrastructure. These points make the adoption of Google Apps for Education a much more realistic proposition for schools.

6.2.2.3 Phase 2-Cycle 2

The prototype e-learning software developed in Phase2-Cycle1 was then revised in accordance with the research findings and the updated pedagogical heuristics resulting from Phase2-Cycle1. The software prototype was now split into two levels (L1 White V03 and L2 Yellow V02). In Phase2–Cycle2, the prototype also implemented gamification that required Learning Management System (LMS) support; hence, the SCORMCloud platform was temporarily replaced by Adobe Captivate Prime.

6.2.2.4 Phase 3

The prototype e-learning software, started in Phase 1, refined in Phase 2, was now finalised in Phase 3 in accordance with the research findings from the Phase2-Cycle2 study and the final set of pedagogical heuristics. The software prototype was updated in accordance with 2016 GCSE Computer Science specifications from OCR, AQA and Edexcel, and split into four levels. The splitting into levels was in accordance with Heuristic 19: Optimise essential processing by segmenting learning material and providing pre-training, and considers the increasing difficulty of the material and the segmenting of learning content into logically-related topics.

1. **Level 1 White, Algorithms and Computational Thinking V0.5.** This level was evaluated as having Content Quality of 85%, a Pedagogical Quality of 74%, and overall Educational Value of 80%. For a detailed breakdown of the evaluation results, please refer to Vol 3 Appendix S.
2. **Level 2 Yellow, Algorithms and Computational Thinking V0.5.** This level was evaluated as having Content Quality of 78%, a Pedagogical Quality of 65%, and overall Educational Value of 71%. For a detailed breakdown of the evaluation results, please refer to Vol 3 Appendix T.
3. **Level 3 Orange, Flowcharts V0.3.** This level was evaluated as having Content Quality of 88%, a Pedagogical Quality of 70%, and overall Educational Value of 79%. For a detailed breakdown of the evaluation results, please refer to Vol 3 Appendix U.
4. **Level 4 Blue, Pseudo-Code V0.3.** This level was evaluated as having Content Quality of 75%, a Pedagogical Quality of 74%, and overall Educational Value of 74%. For a detailed breakdown of the evaluation, results please refer to Vol 3 Appendix V.

The software provided learning material for: algorithms, computational thinking, flowcharts and pseudocode. Level-1 and Level-2 provide foundational concepts on algorithms and computational thinking, whereas Level-3 and Level-4 provide learning material on flowcharts and pseudocode, which are of direct relevance to the pre-, post-test exam used in Phase 3.

In the final study, the prototype software was hosted on SCORMCloud, which in turn was linked to Google Apps for Education.

6.2.3 VARK Learning Styles Instrument

Except for Phase 2-Cycle 2[30], prior to each observation study, an online VARK instrument was administered to collect learning style preferences from the student participants. This instrument is based on the original VARK research by Fleming and Mills (1992), but is tailored to younger people. With Neil Fleming's involvement, the various versions of the instrument are managed under VARK Learn Limited. The instrument and its marking scheme are listed for reference in Vol 3 Appendix I.

6.2.3.1 Validity and Reliability

As a well-established learning styles measurement instrument, the VARK instrument is considered to have high validity. Furthermore, the ready availability of the instrument, its relative simplicity, and the availability of a clear marking scheme, ensure repeatability within this study and across other studies. These underlying characteristics towards repeatability are also strong indicators of the instrument's reliability.

[30] VARK responses were not collected in Phase2–Cycle2 since all participants had previously responded to the instrument.

6.2.4 Survey Instrument

After each observation study, an online survey was administered to collect student rating and opinion on the e-learning software prototype; this was then used to extrapolate towards the underlying pedagogical heuristics used in the design of the software. The survey instrument was developed by the researcher and contained a combination of Likert, rank, and open questions. Prior to its pilot in Phase 1, the survey instrument was reviewed by experienced researchers (members of the supervisory team), and as part of the ethical approval process.

In preparation for each phase/cycle, the instrument was refined, based on previous findings and the objectives of the phase/cycle. Prior to each use, it was again piloted internally, reviewed by experienced researchers (members of the supervisory team) and approved by the ethics committee.

Also, included in the instrument was John Keller's **Instructional Materials Motivation Survey (IMMS)** (2006) which measures student motivation according to the ARCS motivation model (J. Keller 1987).

For reference, the final survey instrument used in Phase 3 is listed in Vol 3 Appendix H.

6.2.4.1 Validity and Reliability

To ensure validity and reliability, the decision was taken to reuse another well-established instrument. Similar rationale as that discussed in section 6.2.3.1 (VARK Instrument Validity and Reliability), was considered in using the IMMS. Additionally, Keller (2006) has documented his own reliability estimates based on Cronbach's alpha, which he conservatively judges to be satisfactory (refer to Table 24). Within Phase 3, Cronbach's alpha was also used to assess the internal reliability of the IMMS results.

Scale	Reliability Estimate (Cronbach α)
Attention	.89
Relevance	.81
Confidence	.90
Satisfaction	.92
Total scale	.96

Table 24: Keller's IMMS Reliability estimate.

The remainder of the survey instrument was new and developed by the researcher specifically for this research. As such, several measures were taken to improve validity and reliability. These measures were more significant in Phase 3 since in Phases 1 and 2 the results of the survey instrument were considered within a qualitative context, and triangulated with the observation study, the LMS results and the focus groups. This triangulation of results is one of the most important indicators of the validity of the Phase 3 survey instrument since it gives multiples measures that validate the survey instrument responses.

The validity and reliability of the survey instrument are further safeguarded in that it has undergone a pilot study and was used (with some adjustments) in both Phase 2 (two cycles) and Phase 3. It should be noted that prior to Phase 3, a survey instrument phase analysis showed that 54% of questions were used in all the previous three iterations, 69.5% of questions were used in two of the last three iterations, and the questions that were changed involved primarily minor wording changes.

The **Content validity** of the survey instrument was safeguarded by the review of experienced researchers in the subject area before each phase.

Alternate-form reliability was employed in the Phase 3 survey instrument by using differently worded questions to measure the same attribute. In this case, the wording is adjusted, and the scale reversed between question pair: 4 A) and 12 A).

Internal consistency reliability was employed in the Phase 3 survey instrument by assessing groups of questions which were intended to measure different aspects of the same concept. In this case, the following questions are measured for internal consistency:

- Questions 4A), 4C), 4D), 4E), 4H), 4I), 4J) and 4K) all measure usability of the prototype software.
- Questions 8A), 8B) and 8C all measure the difficulty of the prototype software.

6.2.5 Technical Specification Document

During each observation study, the students' accessed the e-learning software and the collaborative learning environment. Although both are cloud-based, there remain some technical pre-requisites and checks that need to be carried out in the schools' computer labs by the admin staff, and by the students before home use.

In Phase 1, these pre-requisites and technical checks were communicated via email; however, from Phase 2 onwards, they were communicated in a Technical Specification document that was tailored towards the objectives and technical requirements of each phase and cycle. For reference, the Technical Specification document from Phase 3 is included in Vol 3 Appendix K.

6.2.6 Phase 3 - Pre-test / Post-Test

The pre-, post-test was developed to measure student learning performance in relation to usage of the e-learning software prototype. The test is based on specimen exam papers from Paper 2: Application of computational thinking, of the new Computer Science GCSEs. The exam questions were taken from the following examination boards: EDEXCEL, OCR and AQA. Specimen papers were used since the new Computer Science GCSEs started in September 2016 and were first examined in 2018.

The test was designed to recreate as closely as possible exams for the new specification. There were 31 marks in the test, instructions and information were provided in accordance with exam conditions, and the test was taken in pencil/paper form under exam conditions. The test duration was reduced to 35 minutes in alignment with the reduced number of questions and marks. For reference, the pre-, post-test and marking scheme are in Vol 3 Appendix J.

6.2.6.1 *Validity and Reliability*

The test instrument is considered to have high validity and reliability since: it accurately reflects exam questions on the subject matter; was confirmed as appropriate by the teachers involved in Phase 3; and was confirmed by the teachers as being used under exam conditions. The marking of the tests was guided by official marking schemes from the examination boards, and sample moderation was applied to ensure the marking was fair.

It is important to note that none of the questions are memory based; in terms of Bloom's taxonomy, they all focus on higher-order thinking such as analysing and evaluating. This means that the students were unlikely to memorise the answers in the 2-week period between the pre- and post-test. Additionally, the students were not informed of the correct answers until after the post-test. Before the post-test, students communicated whether they had accessed other learning material on the subject matter, and those that had were removed from the analysis.

6.2.7 Phase 3 - Research Protocol Confirmation Document

Since the Phase 3 study was executed in two schools with three teachers, it was important to ensure each teacher and group followed the same detailed procedures, thereby safeguarding reliability and validity. A Phase 3 Research Protocol Confirmation document was distributed to the teachers ahead of the study, which documented the steps and activities to be followed during the study. The document acted as a checklist for the teachers to confirm they followed the procedures, and to document any potential events or disruptions that could have affected study results. For reference, a completed Research Protocol Confirmation document is included in Vol 3 Appendix L.

6.3 Phase 1 Pilot Findings

As a pilot study, Phase 1 was highly valuable in setting a stable foundation for the research, and identifying the need for several changes in the research direction.

6.3.1 Feedback into Research Methods and Experiment Protocol

Phase 1 provided the following points of direction in relation to the research methods and experiment protocol for later phases.

1. The overall framework of observation study, feedback survey and then focus group, although effort-intensive, is considered successful.
2. As discussed in detail in section 3.4.2.1, the student participants in Phases 1 and 2 are not fully representative of the GCSE Computer Science student population. However, their qualitative student feedback on the e-learning software and the underlying pedagogy remain highly valuable, and transferable to similar contexts.
3. The survey instrument from Phase 1 was carried forward into Phase 2 and 3; however, the survey instrument was too lengthy, therefore was revised to reduce the number of questions.

4. A greater focus was given to comprehensive and uniform participant instructions; this was accomplished by a standard instruction handout.
5. A basic training on the e-learning software and the collaborative learning environment was given before the observation studies in later phases; this was accomplished by a pre-recorded training video.
6. The technical environment specification from Phase 1 was further enhanced before Phase 2. It was updated to outline a detailed and specific target environment for use in the observation study.
7. Before the observation studies in later phases, a more rigorous set of technical checks were executed on the school's computer lab to ensure alignment with the environment specification necessary to run the e-learning software.

6.3.2 E-learning Pedagogy – Change of Focus

Initially, at the research approval stage, it was planned to deliver two separate pedagogical strategies: one for computer science teaching, and one for computer science e-learning software development. However, as the research progressed, this split became quite arbitrary due to the interdependent nature of both pedagogies; hence, they were combined into a single document, which in Phase 1 outlined 36 pedagogical principles.

A more significant change of focus was that originally the research was focused purely on creating e-learning software. Again, as the research matured, it became clear that e-learning software loses value as an isolated entity, and that significant educational value can be gained in integrating the e-learning software within a collaborative learning environment. Hence, the pedagogy was extended to consider collaborative learning.

6.3.3 E-learning Software Development – Change of Focus

One of the original aims of this research was to create an e-learning pedagogy for the development of GCSE Computing e-learning software. Additionally, the pedagogy was originally targeted towards teachers. However, the Phase 1 development process called into question this objective and the intended target audience. What is clear is that the development of quality e-learning software is not a trivial task. Despite the use of one of a leading e-learning Integrated Development Environments (IDE), there were some significant challenges in the development process. E-learning IDEs are very powerful, and offer a wide variety of templates, widgets, integration and e-learning functionality within a relatively moderate learning curve. However, this standard functionality may not always be pedagogically appropriate, offers limited customisation, and can be quite brittle in where it works and under what publication mechanism. This means that an initial prototype may be relatively quick to develop, but professional e-learning software that fully adheres to the pedagogical heuristics requires significant effort, skill, and the experience of an educational technology developer. A more appropriate focus for the pedagogy was therefore the definition of a set of heuristics that guide teachers (and instructional designers) to design e-learning software, or evaluate existing software, for inclusion in their teaching.

6.4 Teacher and Educational Expert Feedback on the E-learning Pedagogy

The teacher and education expert evaluation and input into the e-learning pedagogy spanned across all three phases and included supplementary teacher feedback from the e-learning workshop in Phase 3. This is visually represented in Figure 29.

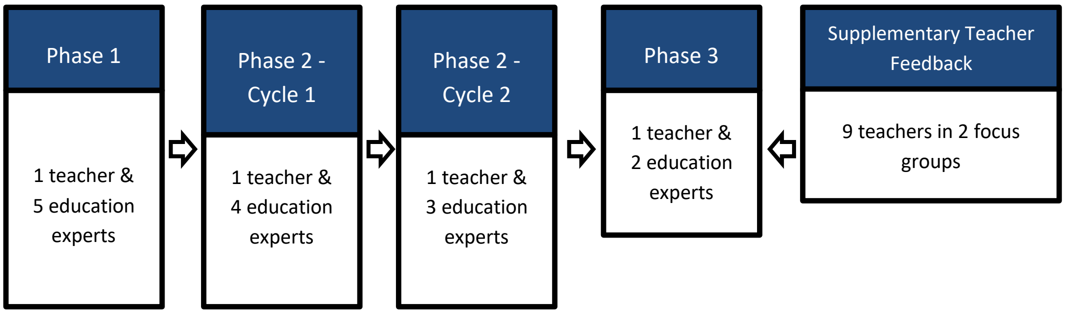


Figure 29: Phase summary of teacher and education expert feedback on e-learning pedagogy

6.4.1 Phase 1: Teacher and Expert Feedback on E-learning Pedagogy

The review of the Phase 1 e-learning pedagogy by five education experts and one teacher is based on the pedagogy document GCSE Computer Science E-Learning Pedagogy v0 7. The evaluation feedback is summarised in Table 25, which is elaborated with richer qualitative description in Vol 2 Appendix A section A.1.

Phase 1
1 teacher and 5 education experts
[+] 1 teacher & 1 expert confirm heuristics appropriate for 15 & 16-year olds. **[+]** 1 teacher & 1 expert confirm heuristics appropriate for computer science. **[+]** No disagreement with any of the heuristics. **[+]** No report of gaps in the heuristic coverage. **[+]** Pedagogy commented as comprehensive. **[±]** Teacher recommends heuristics for collaborative and social learning are more appropriate for home use. **[±]** 1 teacher & 1 expert express some concern over CL1.1 Static illustrations can be better than animations. **[±]** Recommendation to consider gamification, reward and fun. **[±]** Recommendation to update and rephrase heuristic titles for clarity and uniformity.

[±] Action to remove Educational Change and Technology Implementation sections in favour of a Design and Evaluation section.
[±] Not all heuristics are based on a Learning Theory – Action to add Pedagogical Area field to further categorise each heuristic.
[±] Recommendation from education experts 2, 3, and 5 to describe how some heuristics may contradict each other.
[±] IDEA: Map the heuristics according to the different elements of the CS curriculum – Declined, pedagogy is proposed as a toolkit for the teacher to select in context.
[-] 1 expert commented that pedagogy does not explicitly address realistic school context – Action to add Potential Challenges section.
[-] Concern over the non-standard approach to referencing - Clarified that standard academic referencing will be used in the thesis literature review.
[-] Feedback on grammar, spelling, phrasing, clarity of expression and moderating strong wording.
[-] 1 expert commented to avoid political rhetoric.
[-] Concern over appropriateness of some terminology to the teacher audience – Decision to include glossary.

Legend:
[+] Positive Feedback
[±] Mixed Feedback or Recommendation
[-] Adverse Feedback

Table 25: Phase 1 teacher and expert feedback on e-learning pedagogy

6.4.2 Phase2-Cycle1: Teacher and Expert Feedback on E-learning Pedagogy

The review of the Phase2-Cycle1 e-learning pedagogy by four education experts and one teacher is based on the pedagogy document GCSE Computer Science E-Learning Pedagogy v1.2. The evaluation feedback is summarised in Table 26, which is elaborated with richer qualitative description in Vol 2 Appendix A section A.2.

Phase2-Cycle1
1 teacher and 4 education experts
[+] Heuristics included for motivation, computational thinking and gamification. **[+]** 4 of 5 participants confirm heuristics are appropriate for 15 to 18-year olds. • Request to correlate heuristics according to their suitability to DfE Key Stages 4 and 5 learning objectives. **[+]** 3 of 5 participants confirm heuristics are appropriate for computer science education. • Commented that heuristics also focus on underlying skills important to computer science. **[±]** 2 of 5 participants confirm feasibility of the heuristics to be implemented in a high school environment. • Commented that potential challenges to implementation are documented and addressed in the pedagogy. **[+]** 4 of 5 participants confirmed there is balanced pedagogical coverage in the heuristics.

- No additional heuristics identified.

[+] Teacher feedback supports the recommended moderate connectivist approach.

[+] Teacher feedback supports pedagogy heuristics on engagement and motivation, and visual learning.

[±] Pedagogy is proposed as a toolkit of which specific tools (heuristics) are selected based on teacher or designer judgement.

[±] Computational thinking queried as to whether and exactly how it should fit within the pedagogy.

[±] Recommendation to further categorise heuristics, and where they become important.

- Decision to include a benefits matrix that visually represents the intended benefits of each heuristic.

[+] Overall feedback is positive regarding the structure and readability of the pedagogy document. However, still room for improvement:

> **[±]** Additional comments to update and rephrase heuristic titles for clarity and uniformity;
>
> **[±]** Recommendation on how to sequence heuristics differently, and how some heuristics should become sub-heuristics;
>
> **[-]** Document increased in size to 130 pages - document to be shortened;
>
> **[-]** Reduce number of heuristics and evaluation criteria, too much information for teacher audience;
>
> **[-]** Usability of the document for the intended teacher audience is questioned;
>
> **[-]** Commented that phrasing and consistency of coverage in the pedagogy needs further review;
>
> **[-]** Recommendation that related heuristics sections need further work to effectively reflect the heuristic interrelationships; and
>
> - Decision to include interrelationship matrix that shows heuristics support or conflict with each other.
>
> **[-]** Concern over non-standard approach to referencing – reaffirmed that standard academic referencing will be used in the thesis literature review – Reference section removed from pedagogy.

Legend:
[+] Positive Feedback
[±] Mixed Feedback or Recommendation
[-] Adverse Feedback

Table 26: Phase2-Cycle1 teacher and expert feedback on e-learning pedagogy

6.4.3 Phase2-Cycle2: Teacher and Expert Feedback on E-learning Pedagogy

The review of the Phase2-Cycle2 e-learning pedagogy from three education experts and one teacher is based on the pedagogy document GCSE Computer Science E-Learning Pedagogy v1.5. The evaluation feedback is summarised in Table 27, which is elaborated with richer qualitative description in Vol 2 Appendix A section A.3.

Phase2-Cycle2
1 teacher and 3 education experts
[+] All participants confirm heuristics are appropriate for 15 to 18-year olds. • Pedagogical heuristics provide support for DfE Key Stage 4 objective 1 and strong support for objective 2. • Pedagogical heuristics provide strong support for DfE Key Stage 5 learning objectives 1 through 4. **[+]** All participants confirm heuristics are appropriate for computer science education. **[±]** All education experts confirm feasibility of the heuristics to be implemented in a high school environment. • Teacher neither agrees nor disagrees. "*Very little time provided for student-content which deepens learning*". **[+]** All participants confirmed there is balanced pedagogical coverage in the heuristics. • Teacher recommends more emphasis on learning from mistakes. **[+]** Shortening and restructuring of pedagogy document is well received by participants. **[+]** All participants confirmed that the educational benefits of each heuristic are clearly described. **[±]** Educational Benefits Matrix confirmed as valuable, but context of use and limitations of the matrix need to be communicated. **[+]** All participants confirm the interrelationships between heuristics are clearly described. **[-]** The size and intricacy of the interrelationship matrix is a challenge for legibility. **[+]** Decision to supplement with an interrelationship map. **[+]** Minor comments relating to spelling, grammar and phrasing. **[+]** Teacher gives very positive comments on appropriateness of pedagogy. **[±]** Expert comments that the pedagogy is a valuable and rich resource for teachers, but that would still require non-trivial efforts for schools to fully utilise. **[-]** Appendices document requires further work to be brought to the standard of the pedagogy.

Legend:
[+] Positive Feedback
[±] Mixed Feedback or Recommendation
[-] Adverse Feedback

Table 27: Phase2-Cycle2 teacher and expert feedback on e-learning pedagogy

6.4.4 Phase 3: Teacher and Expert Feedback on E-learning Pedagogy

The review of the Phase 3 e-learning pedagogy from two education experts and one teacher provided the feedback outlined in this section; this feedback was based on the pedagogy document GCSE Computer Science E-Learning Pedagogy v1.7b(CLEAR).

In Phase 3, the evaluation feedback on the e-learning pedagogy had plateaued and was nominal; hence it is included in this section rather than referenced in an appendix.

Education Expert 2 provided feedback in the Pedagogy Evaluation Feedback document; however, this mainly reinforced the same positive comments as Phase2-Cycle2. Education Expert 3 provided some small feedback in a short-written response. Teacher 4, responded in the feedback document; however, the comments were universally positive. The remainder of this section will briefly outline the new comments from the education experts and the new feedback from Teacher 4.

6.4.4.1 Education Expert Feedback

Education Expert 3 offered positive comments and confirmation on:

1. The e-learning pedagogy document overall,
2. The heuristic summary table at the beginning of the document,
3. The educational benefits matrix,
4. The heuristics interrelationship map, and
5. That the appendices document was now acceptable.

One constructive comment from Education Expert 3 was to query the red counteractive relationships in the heuristics interrelationship map. After further discussion, it was agreed that these counteractive relationships should be re-reviewed by the researcher, and a guidance note placed on the diagram.

6.4.4.2 Teacher Feedback

In addition to reviewing the e-learning pedagogy, Teacher 4 and his GCSE class also participated in the Phase 3 experiment to use the e-learning prototype in a school context. He offered Strong Agreement to:

1. Appropriateness of heuristics for 15 to 18 years olds (Key Stages 4 & 5),
2. Appropriateness of heuristics for computer science education,
3. Feasibility of heuristics to be implemented in a high-school environment,
4. The balanced pedagogical coverage,
5. The education benefits of each heuristic are clearly described, and
6. The interrelationships between heuristics are clearly described

Teacher 4 commented that the pedagogy "*reflects on a new generation of learners"*, and in relation to its appropriateness for computer science, stated that:

"Yes, it is as Computer Science can be boring. This study shows how it can be made more interactive and interesting." [Teacher 4]

Considering both the pedagogy and his school's involvement in the Phase 3 study, Teacher 4 advised that the *"students have made massive progress and learnt a lot by following the e-learning software based on pedagogy."*

As a final comment, Teacher 4 advised that the:

"Research is very clear and it has a strong connection with all the activities carried out during school activities."

6.4.5 Supplementary Teacher Feedback on the E-learning Pedagogy from the Phase 3 Workshop

The Phase 3 study for the e-learning evaluation protocol was encompassed within a teacher workshop focused on e-learning and effective teaching practices for high-school computer science. A substantial portion of this workshop was dedicated to educating the teachers on the e-learning heuristics. This instructional session, and the teachers' access to the evaluation protocol document, indicate a reasonable grounding in the e-learning heuristics. However, at this point, these teachers did **not** have access to the e-learning pedagogy document and the opportunity to evaluate it in detail. It is for this reason that the strength of the following findings should not be overstated; the strength of these findings does not equate with previous in-depth evaluations from teachers and education experts. Nevertheless, they do offer supporting evidence of the appropriateness and validity of the e-learning heuristics.

This feedback is based on the pedagogy document GCSE Computer Science E-Learning Pedagogy v1.7b(CLEAR), it is summarised in Table 28, which is elaborated with richer qualitative description in Vol 2 Appendix A section A.4.

Supplementary Teacher Feedback
9 teachers in 2 focus groups
[±] Strength of findings is weaker since feedback is based on pedagogy seminar, not detailed review of pedagogy document. **[+]** Both focus groups offered consensus of appropriateness of the heuristics for 15 to 18-years-olds. **[+]** Both focus groups offered consensus of appropriateness of the heuristics for computer science. **[+]** Overall, both groups offered consensus that the heuristics offered balanced pedagogical coverage. [-] One teacher disagreed, commenting that there is no balance, and there are many gaps and weak areas. **[±]** Measured response regards the feasibility of the heuristics to be implemented in a high-school environment. **[+]** One teacher offered positive support for approaches used in pedagogy to summarise heuristic interrelationships and key benefits.

Legend:
[+] Positive Feedback
[±] Mixed Feedback or Recommendation
[-] Adverse Feedback

Table 28: Supplementary teacher feedback on the e-learning pedagogy from the Phase 3 workshop

As reflected in Figure 29, the e-learning pedagogy received detailed feedback and input from a total of five education experts and four in service teachers, with further supplementary feedback from an additional nine in service teachers in the Phase 3 workshop. This iterative and incremental feedback spanned across three phases, including two cycles in Phase 2.

In summary, feedback in all phases was mainly positive and always constructive. Throughout there was feedback on grammar, spelling, phrasing, and clarity of expression, this gradually tapered off to almost nothing in Phase 3. In Phase 1 and Phase 2-Cycle 1 there was some advice to rephrase heuristic titles for clarity and uniformity, to re-sequence some heuristics and restructure some heuristics as sub-heuristics, thereby facilitating a more natural flow and grouping. Throughout, the pedagogy was confirmed to be appropriate for the target age group, and in Phase 2-Cycle 2 it was evaluated and confirmed to be appropriate for DfE Key Stages 4 and 5 learning objectives (i.e. 15 to 18-year olds). Throughout, there was confirmation from education experts and teachers that the heuristics are appropriate for computer science education, this confirmation strengthened across the phases as the pedagogy matured. Throughout the phases the pedagogy was commented as balanced and comprehensive; there was no disagreement with any of the heuristic and no report of gaps in the heuristic coverage. Although in Phase 1 there was some minor comment on one sub-heuristic and a response from one education expert to consider gamification, reward and fun. The latter comment gave further stimulus towards the inclusion of heuristics on motivation, computational thinking and gamification in Phase 2-Cycle 1. In Phase 1, one expert commented that the pedagogy did not explicitly address a realistic school context, this led to the addition (in Phase 2-Cycle 1) of the potential challenges section for each heuristic. In follow on phases there was increasing strength of confirmation of the feasibility of the heuristics being implemented in a high school environment. However, there was always some residual concern that little time is allocated in schools towards deep learning, also that change in a school context can be difficult thereby the pedagogy would still require non-trivial efforts for schools to fully utilise.

By Phase 3, the evaluation of the e-learning pedagogy remained aligned with the positive feedback received in Phase 2-Cycle 2, constructive comments had plateaued and were almost non-existent. The detailed feedback from the Phase 3 teacher was overwhelmingly positive and was supplemented by broadly positive feedback from the workshop teachers.

6.5 Phase 1 and 2 – Findings from Student Usage of E-learning Software Prototype

As discussed in Chapter Three, Phase 1 and 2 were used as exploratory phases to iteratively develop the e-learning pedagogy and test aspects of that pedagogy in depth within a school context. A small sample of GCSE students was used within an observation study, which was later triangulated with survey and focus group results.

The student participants have already been discussed in detail; however, for a brief recap of student participants in Phase 1 and 2, please refer to Table 29.

	Phase 1	Phase2 Cycle 1	Phase2 Cycle 2
Student Group 1	7	6	3
Student Group 2		3	2

Table 29: Phase 1 and 2 student participants

The results discussed in this section are grouped thematically across the phases; however, not all themes received research focus in each phase and cycle. Figure 30 gives a visual representation of how the themes were addressed across the phases.

Figure 30: Thematic coverage of results in Phase 1 and 2

As discussed previously, in the interest of brevity, abridged findings are presented in this section, but are further elaborated upon in Vol 2 Appendix B. These findings are summarised in Table 30 through Table 45.

Usability and Navigation
Phase 1 and both cycles of Phase 2

[+] Positive student feedback regarding the ease of use of the e-learning software.
[-] Negative student feedback regarding the reliability of the e-learning software.
    [-] As the software became more sophisticated fewer of the IDE’s standard outputs and less standard functionality could be used, leading to an increase in bugs and usability concerns.
[+] Positive student feedback on navigation and program control.
    [+] Strong positive support for heuristics on restricted navigational control (Heuristics 21 and 21.1).
    [+] Positive student feedback on restricted navigation tree.
[+] Positive student feedback on instructions and prompt messages.
    [-] Observation that students were not reading screen instructions; hence missed within-screen navigation.
    [-] Learning Object Icons, (signposting educational content) were being overlooked.
    [±] Weakly positive feedback on mitigation steps to make instructions, within-screen navigation and learning object icons more attention-grabbing.
    [±] Weak response to pre-training video introducing the e-learning software and CLE.
        [±] Pre-training video is broken into individual tutorial videos.

	[+] Students recommend tutorials not be placed at the start of the software, but spread as needed across the software screens.
Heuristics Impacted:	17: Integrate words and graphics together, instead of words alone. 19: Optimise essential processing by segmenting learning material and providing pre-training. 21: Provide restricted navigational control in the e-learning software. 21.1: Provide consistent navigational elements and signposts for learning.

Legend:
[+] Positive Feedback
[±] Mixed Feedback or Recommendation
[-] Adverse Feedback

Table 30: Phase 1 and 2 summary findings for usability and navigation

Learning Styles and Multi-Modal Learning	
Phase 1 and Phase2-Cycle1	
[+] VARK results show comparative balance between the modalities. **[+]** Positive student feedback on the use of varying methods to represent the same educational concepts. **[+]** Negative response to Phase 1 text bias, offers supporting evidence towards multi-modal approach.	
Heuristics Impacted:	16: Use multi-modal learning approaches. 16.1: Support visual modal preference. 16.2: Support aural modal preference. 16.3: Support read-write modal preference. 16.4: Support kinaesthetic modal preference.

Legend:
[+] Positive Feedback
[±] Mixed Feedback or Recommendation
[-] Adverse Feedback

Table 31: Phase 1 and 2 summary findings for learning styles and multi-modal learning

Learning Object Ranking	
Phase 1 and Phase2-Cycle1	
[±] Learning object rankings between two phases are not consistent, but show some preference towards visual and active learning object types. **[-]** Negative ranking is consistent for audio and collaborative activities.	
Heuristics Impacted:	4: Use problem-based learning (PBL) to facilitate learning. 4.1: Use worked examples to support problem-based learning.

	6.2: Exemplify computational thinking in problem-solving activities. 7: Distribute well-designed practice activities across the lesson to support learning. 9: Use social-interaction to increase learning and promote higher-order thinking. 11: Use collaborative learning activities. 16.1: Support visual modal preference. 16.2: Support aural modal preference. 17: Integrate words and graphics together, instead of words alone. 17.1: Apply contiguity by aligning words (audio or screen text) with corresponding graphics. 17.2: Representing words as audio, on-screen text or both.

Legend:
[+] Positive Feedback
[±] Mixed Feedback or Recommendation
[-] Adverse Feedback

Table 32: Phase 1 and 2 summary findings for learning object ranking

Understanding and the Zone of Proximal Development	
Phase 1 and both cycles of Phase 2	
[+] Positive student feedback that educational material was represented in a clear and understandable way – Supports many of the heuristics. **[+]** Positive student feedback that there was no need to supplement the e-learning software with further textbook reading. **[±]** In Phase2-Cycle2, students reported that educational material was at the right level and assessment activities were at the right level or a little difficult. **[-]** In Phase2-Cycle2, students learning performance in quiz results was unfavourable: **[-]** Poor question design; **[+]** Identified areas for improvement of question design; **[±]** Mixed student feedback on restricting number of attempts on a question; **[-]** Students tired due to study being after exam period; and **[-]** Students not committed to passing since acknowledged as a voluntary research study. **[±]** Students avoided reviewing learning material even when guided to do so by the software. **[-]** Students preferred to guess on last attempt.	
Heuristics Impacted:	1: Use authentic educational material, examples and activities. 4.1: Use worked examples to support problem-based learning. 7: Distribute well-designed practice activities across the lesson to support learning. 7.1: Provide explanatory feedback to practice activities to promote learning. 8: Provide scaffolding to advance learning progress. 9: Use social-interaction to increase learning and promote higher-order thinking. 10: Engage learners in a challenge; target learning towards the zone of proximal development (ZPD). 16: Use multi-modal learning approaches.

	16.1: Support visual modal preference. 16.2: Support aural modal preference. 16.3: Support read-write modal preference. 16.4: Support kinaesthetic modal preference. 17: Integrate words and graphics together, instead of words alone. 18: Avoid adding learning content that does not directly support your instructional goal. 19: Optimise essential processing by segmenting learning material and providing pre-training. 20: Use a conversational style in screen text and audio narration. 21.1: Provide consistent navigational elements and signposts for learning.

Legend:
[+] Positive Feedback
[±] Mixed Feedback or Recommendation
[-] Adverse Feedback

Table 33: Phase 1 and 2 summary findings for understanding and the zone of proximal development

Visuals	
Phase 1 and Phase2-Cycle1	
[+] The importance to students of visual elements is reflected in Phase 1 and 2 feedback. **[+]** Positive student feedback that the visual elements are meaningful. **[-]** Comparatively weaker student response on whether the visual elements are aesthetically appealing. **[+]** Positive student feedback that the visual elements are engaging. **[+]** Positive student feedback that the visual elements supported their understanding of the subject matter. **[+]** Findings are aligned with pedagogy which focuses on meaningful and engaging visual elements that support learning, with lesser focus on the aesthetic appeal.	
Heuristics Impacted:	16.1: Support visual modal preference. 17: Integrate words and graphics together, instead of words alone. 17.1: Apply contiguity by aligning words (audio or screen text) with corresponding graphics.

Legend:
[+] Positive Feedback
[±] Mixed Feedback or Recommendation
[-] Adverse Feedback

Table 34: Phase 1 and 2 summary findings for visual learning material

Text	
Phase 1 and both cycles of Phase 2	
[+] Throughout Phase 1 and 2, student feedback shows recognition that text material is important in supporting their understanding of subject matter. **[-]** Heavy text bias in Phase 1 prompted negative student response. **[+]** After corrective action in Phase2-Cycle1, there were no further negative comments in relation to text content.	
Heuristics Impacted:	16.3: Support read-write modal preference. 17: Integrate words and graphics together, instead of words alone. 17.1: Apply contiguity by aligning words (audio or screen text) with corresponding graphics. 20: Use a conversational style in screen text and audio narration.

Legend:
[+] Positive Feedback
[±] Mixed Feedback or Recommendation
[-] Adverse Feedback

Table 35: Phase 1 and 2 summary findings for text learning material

Activities and Active Learning	
Phase 1 and both cycles of Phase 2	
Activities are considered to be Problem-Solving, Games, Simulations, Assessment and Quizzes. **[+]** Strong positive support that activity-based (interactive) components support student understanding of subject matter. **[+]** Positive student feedback that the assessment activities in the e-learning software encouraged them to think, and work through problems, instead of recounting from memory. **[±]** Partially diverging feedback in Phase2-Cycle2, where students agreed that the e-learning software also encouraged them to recall previous knowledge to answer the questions. **[+]** Overall, students agreed the e-learning software prepared them for the assessment activities. **[+]** Positive student feedback that activity-based (interactive) components are engaging. **[±]** Choice of Virtual Manipulation Environment identified as critical for student engagement and usage.	
Heuristics Impacted:	1: Use authentic educational material, examples and activities. 2: Prompt reflective practice to support learning. 4: Use problem-based learning (PBL) to facilitate learning. 4.1: Use worked examples to support problem-based learning. 5: Integrate learning into long-term memory by using authentic examples, and non-trivial practice and problems. 6.2: Exemplify computational thinking in problem-solving activities.

	7: Distribute well-designed practice activities across the lesson to support learning. 7.1: Provide explanatory feedback to practice activities to promote learning. 14.3: Build "Confidence" to increase learner motivation. 14.4: Build "Satisfaction" to increase learner motivation. 15.1: Integrate gamification elements tightly within existing learning processes. 16.4: Support kinaesthetic modal preference.

Legend:
[+] Positive Feedback
[±] Mixed Feedback or Recommendation
[-] Adverse Feedback

Table 36: Phase 1 and 2 summary findings for activities and active learning

Video	
Phase 1 and Phase2-Cycle1	
[±] In spite of the drop in ranking between Phase 1 and Phase 2-Cycle1, videos remain an important part of the e-learning software. [±] Mixed feedback between survey results and focus group; focus group offered clarification and more positive response on videos. **[+]** Videos are a valuable tool in the support of visual modal preference (heuristic 16.1), and visualisation approaches remain important within the pedagogy.	
Heuristics Impacted:	16.1: Support visual modal preference.

Legend:
[+] Positive Feedback
[±] Mixed Feedback or Recommendation
[-] Adverse Feedback

Table 37: Phase 1 and 2 summary findings for video learning material

Computational Thinking	
Phase2-Cycle1	
[+] Positive student feedback that the e-learning software helped them to understand what computational thinking is. **[±]** Student response remains positive, but progressively weakens between recognising computational thinking concepts and being able to use them. **[±]** The e-learning prototype did not provide enough opportunities to exemplify and practice computational thinking (weak support for heuristic 6.2).	
Heuristics Impacted:	6: Support problem-solving through computational thinking.

	6.1: Build a foundation for computational thinking. 6.2: Exemplify computational thinking in problem-solving activities.

Legend:
[+] Positive Feedback
[±] Mixed Feedback or Recommendation
[-] Adverse Feedback

Table 38: Phase 2 summary findings for computational thinking

<table>
<tr><th colspan="2">Collaborative Learning</th></tr>
<tr><td colspan="2">Phase 1 and Phase2-Cycle1</td></tr>
<tr><td colspan="2">[-] Collaborative learning was consistently ranked low.

[±] Student feedback on whether collaborative activities supported their understanding of the subject matter is mixed.

[-] Collaborative learning activities were underutilised by the students in Phase 1 and Phase2-Cycle1.

[+] Students understand at a conceptual level the reasons and value of collaborative activities.

[+] Focus group responses are positive towards collaborative learning.

[±] Technology-enhanced collaborative learning not applicable in class and should be used for homework.

[±] There remains a learning curve for technology-enhanced collaborative learning since it is not the traditional way of working in school.

[±] Research and experiment design was not conducive to evaluating collaborative learning since it was primarily in class, for a short period of time, and voluntary.

[±] Research findings cannot be taken at immediate face value; they require a more complex and in-depth analysis and interpretation.

[-] The e-learning software did not consider the technical affordances of mobile devices or the responsive design necessary for mobile devices.</td></tr>
<tr><td>Heuristics Impacted:</td><td>9: Use social-interaction to increase learning and promote higher-order thinking.

11: Use collaborative learning activities.

11.1: Support collaborative and situated learning via mobile devices.

12: Develop and nurture networks to support learning.</td></tr>
</table>

Legend:
[+] Positive Feedback
[±] Mixed Feedback or Recommendation
[-] Adverse Feedback

Table 39: Phase 1 and 2 summary findings for collaborative learning

Audio	
Phase 1 and both cycles of Phase 2	
[-] In both phases, audio material has consistently been ranked low, but requested to remain, based on the following conditions: **[±]** Audio quality must be good. **[±]** Mute button must be available. **[+]** E-learning software should give support to either enable / disable audio, and must remain pedagogically effective even when audio is disabled.	
Heuristics Impacted:	16.2: Support aural modal preference. 17: Integrate words and graphics together, instead of words alone. 17.1: Apply contiguity by aligning words (audio or screen text) with corresponding graphics. 17.2: Representing words as audio, on-screen text or both. 20: Use a conversational style in screen text and audio narration.

Legend:
[+] Positive Feedback
[±] Mixed Feedback or Recommendation
[-] Adverse Feedback

Table 40: Phase 1 and 2 summary findings for audio learning material

Authentic Learning vs Avoiding Overload	
Phase 2 both cycles	
[±] Tension between the following heuristics: • 1. Use authentic educational material, examples and activities. • 18. Avoid adding learning content that does not directly support your instructional goal. **[±]** Student preference is towards Heuristic 1: Use authentic educational material, examples and activities. **[+]** Support to metacognitive decision making by using a red "i" to indicate additional information that is non-examinable.	
Heuristics Impacted:	1: Use authentic educational material, examples and activities. 18: Avoid adding learning content that does not directly support your instructional goal.

Legend:
[+] Positive Feedback
[±] Mixed Feedback or Recommendation
[-] Adverse Feedback

Table 41: Phase 2 summary findings for authentic learning vs avoiding overload

Connectivism and the Web	
Phase 1 and Phase2-Cycle1	

[±] Students understand that a critical appraisal of the information found on the web is necessary since the source and quality of information may be unreliable.
[±] Students' survey responses showed a weak preference towards the e-learning software compared to using the web for their subject learning.
    [+] Students perceive e-learning software to be comprehensive and prefer the structure of having one place to learn from.
    [±] Students wish to avoid the wasted time in searching the web and evaluating whether the information they find is correct.
        [+] E-Learning software links to other resources, mitigating the previous point.
[+] Findings support moderate connectivist approach recommended in the e-learning pedagogy.	

Heuristics Impacted:	1.1: Ensure the currency of learning material. 11: Use collaborative learning activities. 12: Develop and nurture networks to support learning.

Legend:
[+] Positive Feedback
[±] Mixed Feedback or Recommendation
[-] Adverse Feedback

Table 42: Phase 1 and 2 summary findings for connectivism and the web

Motivation	
Phase 1 and both cycles of Phase 2	

[+] Positive student feedback that it is more interesting to use the e-learning software to learn computing than the textbooks.
[+] Positive student feedback that the students could use the e-learning software for independent study.
[+] Positive student feedback that the e-learning software has increased the students' overall enthusiasm and interest in computing.
[±] Overall IMMS results are consistent across Phase 1 and 2, at approximately 3.67 from 5.
    [±] Considering the iterative changes in the software, the consistency across phases may be viewed as discouraging.
    [±] Must be considered within the context that many aspects of the software remain unchanged between versions, and the student participants also remain the same; hence, some of the novelty and motivation value is lost.	

Heuristics Impacted:	1: Use authentic educational material, examples and activities. 7: Distribute well-designed practice activities across the lesson to support learning. 13: Use constructivist approaches to increase intrinsic motivation in the learner. 14: Use the concepts of Attention, Relevance, Confidence and Satisfaction (ARCS) to attain and sustain learner motivation.

	14.1: Use "Attention" grabbing strategies to increase learner motivation. 14.2: Explain the "Relevance" of the learning material to increase motivation. 14.3: Build "Confidence" to increase learner motivation. 14.4: Build "Satisfaction" to increase learner motivation.

Legend:
[+] Positive Feedback
[±] Mixed Feedback or Recommendation
[-] Adverse Feedback

Table 43: Phase 1 and 2 summary findings for motivation

Gamification	
Phase2-Cycle2	
[+] Intrinsic aspects of gamification already in e-learning software. **[+]** Extrinsic gamification elements included in the software in Phase-2-Cycle2. ○ Support for levels, points, badges and a leaderboard. **[±]** Student survey response to extrinsic gamification elements is weakly positive. **[-]** Focus group discussion shows students to be unenthusiastic about points and badges. **[-]** Challenges: **[-]** Implementation of extrinsic gamification elements directly tied to LMS support. **[-]** Ad-hoc definition of triggers for achievements not supported by LMS. **[-]** Limited set of award triggers supported by the LMS: specified at module level, coarse granularity and not supporting the pedagogy. **[-]** Inappropriate to challenge the student participants. **[-]** Student feedback on leaderboard functionality is mixed. **[+]** Student survey response to the leaderboard's motivational value is positive in the scenario that a student is underperforming. **[±]** Student survey response to the leaderboard's motivational value is mixed in the scenario that a student is performing well. **[±]** Focus group highlighted concerns that a leaderboard may further demotivate students who are not performing well, and may signal high performers to relax if they are well ahead of their classmates.	
Heuristics Impacted:	15: Use gamification to increase motivation and learning performance. 15.1: Integrate gamification elements tightly within existing learning processes. 15.2: Build extrinsic gamification elements on top of existing learning processes.

Legend:
[+] Positive Feedback
[±] Mixed Feedback or Recommendation
[-] Adverse Feedback

Table 44: Phase 2 summary findings for gamification

Recreating Books	
Phase 2 both cycles	
[±] Students requested a more explicit structure in the e-Learning software. **[±]** Mimic a traditional chapter format, with the chapter learning objectives, learning material, review questions and finally a learning summary. **[±]** Software updated by breaking the learning material into levels, with learning objectives, learning material and review questions. **[+]** Positive student feedback that levels helped in estimating progress. **[+]** Positive feedback that levels helped motivate students to progress to the next level.	
Heuristics Impacted:	19: Optimise essential processing by segmenting learning material and providing pre-training. 21: Provide restricted navigational control in the e-learning software. 21.1: Provide consistent navigational elements and signposts for learning.

Legend:
[+] Positive Feedback
[±] Mixed Feedback or Recommendation
[-] Adverse Feedback

Table 45: Phase 2 summary findings for recreating books

It should be noted that the preliminary findings from Phase 1 were presented at the EAPRIL[31] 2014 Conference and published in the associated conference proceedings (Yiatrou et al. 2014). The preliminary findings from Phase 2-Cycle1 were presented at the FedCSIS[32] 2016 Conference and published in the associated conference proceedings (Yiatrou et al. 2016).

[31] European Association for Practitioner Research on Improving Learning

[32] Federated Conference on Computer Science and Information Systems

6.6 Phase 3 Results

As a recap, Phase 3 used a convergent parallel mixed method design with a quantitative priority, in which students:

1. Undertook a pre-test;
2. Responded on a standard VARK measurement instrument;
3. Undertook learning (under controlled conditions) on computational thinking and algorithms, using the four levels of e-learning software and the collaborative learning environment;
4. Undertook a post-test; and
5. Responded on a survey instrument.

With reference to the above, this section reports on the:

1. Student responses to the survey instrument, such as their perception of the e-learning software and their level of motivation,
2. Student VARK profiles,
3. Student learning performance related to pre- post-test results.

As a guiding reference, the key results from Phase 3 are summarised in Table 46 and Table 47.

Student Perception of E-learning Software
The average student response to the survey instruments indicated: **[+]** Broadly positive feedback in terms of the usability of the e-learning software. **[-]** Usability concerns in relation to bugs in the prototype software and the speed/responsiveness of the cloud-based delivery. **[+]** Broadly positive feedback on the impact that the different educational components had on students' perceived understanding. **[-]** Response on the audio content was non-committal on whether audio helped students' understanding of the subject matter. **[+]** Agreement that use of different methods to represent the same learning content helped understanding (i.e. multi-modal learning). **[+]** Learning material, practice activities and quiz questions were at the right difficulty level. **[±]** Neither agreement nor disagreement on whether the students needed to supplement the e-learning software with further textbook reading, or whether they felt the need to ask their teacher for support in understanding the learning material. **[±]** Neither agreement nor disagreement on whether, after completing the 4-levels of the e-learning software, they felt confident of passing a test on the subject matter. **[±]** Neither agreement nor disagreement on whether the students' felt it more interesting to use the e-learning software to learn computing than the textbooks. **[+]** Agreement that the students could use the e-learning software for independent study to learn computing. **[+]** Agreement that the e-learning software had increased their overall enthusiasm and interest in computing. **[+]** A weakly positive feedback of moderately true to the IMMS motivational sub-categories of attention, relevance, confidence and satisfaction.

[+] Overall IMMS results are weakly positive, with a moderately true response of 3.15 from 5.

[±] Except for attention vs relevance, the summation of student responses on the IMMS sub-categories for the e-learning prototype are broadly balanced and aligned.

[+] Except for visual vs. kinaesthetic, the summation of student responses on the VARK sub-categories are comparatively balanced and aligned.

Legend:
[+] Positive Feedback
[±] Mixed Feedback or Recommendation
[-] Adverse Feedback

Table 46: Phase 3 - Summary of student perception of e-learning software

Student Learning Performance

The average student learning performance, and engagement with the e-learning software and CLE indicated that:

[±] The median average student engagement with the e-learning software, excluding CLE, was 196 minutes.

[±] The median average student engagement with levels 3 and 4 of the e-learning software, excluding CLE, was 64 minutes.

[-] Student engagement with the CLE and the assignment activities was inadequate.

[+] The results between both schools in relation to Pre-Test, Post-Test and %Change are **not** statistically different.

[+] Parametric and non-parametric statistical analysis indicates an increase of over 19% points between the pre- and post-test.

[+] Parametric tests indicate that we cannot reject the null hypothesis that the %Pre-Test mean is equal to the hypothesised GCSE Grade F target value.

[+] Parametric tests indicate that we cannot reject the null hypothesis that the %Post-Test mean is equal to the hypothesised GCSE Grade C target value.

Non-parametric Correlation Analysis was broken into two tiers:

1. Tier 1 correlations include:
    a. A medium positive correlation between %Post-Test result and Level-2 time
    b. A medium negative correlation between KS4 Prediction and Level-1 Time
    c. A medium positive correlation between KS4 Prediction and Level-4 Time
    d. A medium positive correlation between KS4 Prediction and Level-3 and -4 Combined Time
    e. A medium positive correlation between IMMS Overall and Level-2 Time
    f. A medium negative correlation between %Change and the students' relative feelings of being overloaded by multi-modal learning
2. Tier 2 correlations include:
    a. A small positive correlation between %Post-Test result and All Levels Combined Time
    b. A small negative correlation between %Post-Test result and VARK Aural result
    c. A small positive correlation between %Post-Test result and VARK Kinaesthetic result
    d. A small negative correlation between %Change and Level-3 time
    e. A medium positive correlation between IMMS Relevance and Level-2 Time
    f. A medium positive correlation between IMMS Relevance and Level-3 and -4 Combined Time
    g. A medium positive correlation between IMMS Satisfaction and Level-3 Time
    h. A medium positive correlation between IMMS Satisfaction and Level-3 and -4 Combined Time
    i. A medium positive correlation between IMMS Overall and Level-3 and -4 Combined Time
    j. A medium positive correlation between %Post-Test result and the students' perception of the e-learning software being easy to use

k. A medium positive correlation between %Post-Test result and the students' perception of the e-learning software being reliable (i.e. does not contain bugs or errors)

l. A medium negative correlation between %Post-Test result and the students' relative feelings of being overloaded by multi-modal learning

Legend:
[+] Positive Feedback
[±] Mixed Feedback or Recommendation
[-] Adverse Feedback

Table 47: Phase 3 - Summary of student learning performance

6.6.1 Phase 3 Participants – Merging of Groups

The Phase 3 study was comprised of two UK public schools offering the Computer Science GCSE (2016 Specification). The Phase 3 student sample (66 students) is discussed in section 3.6.2.2, and is deemed representative of the wider GCSE student population.

To strengthen the statistical analysis in Phase 3, the response data from both schools were merged into a single group. This decision was taken based on the following:

1. Both teachers responded on the Phase 3 Research Protocol Confirmation document, showing that both sets of students undertook the study in the same controlled conditions.
2. Independent sample T-Tests of Pre-Test, Post-Test and %Change results showed that the null hypothesis could **not** be rejected.

School1 Pre-Test results (M=5.11, SD = 3.22) were similar to the Pre-Test results from School2 (M=4.71 SD=3.96) conditions; t(46)=0.38, p=.70.

School1 Post-Test results (M=10.96, SD = 4.67) were similar to the Post-Test results from School2 (M=10.81 SD=3.83) conditions; t(46)=-0.12, p=.90.

School1 %Change results (M=18.488, SD = 12.77) were similar to the %Change results from School2 (M=19.66 SD=11.71) conditions; t(46)=-0.22, p=.83.

The above t-test results do not prove the two groups are equivalent, but gives an indication that the responses from both groups are **not** statistically different, and can be combined without negative impact to statistical analysis.

6.6.1.1.1 Reporting of Outliers

In alignment with section 3.6.5.3, which discusses the treatment of outliers, this section will primarily report descriptive statistics including outliers, but will also report as a reference, descriptive statistics without outliers. This approach will indicate the potential impact of the outlier(s), and give input on whether subsequent statistical tests should be carried out with or without outliers.

6.6.2 Student Perception of the E-learning Software

6.6.2.1 Participants

From the 66 student participants in Phase 3, 47 participants responded to the survey instrument: 28 participants from school1 and 19 participants from school2. There was minimal non-response to the survey questions, except for the IMMS question set and the 2 ranking questions; hence, those were analysed separately.

6.6.2.2 Survey Response

6.6.2.2.1 Response on E-learning Usability

Based on the following standard Likert scale: 1 Strongly Disagree, 2 Disagree, 3 Neither Agree nor Disagree, 4 Agree and 5 Strongly Agree, the student participants gave broadly positive feedback on the usability of the prototype e-learning software.

With reference to Table 48, the median student response showed **agreement** (4) with the following statements:

1. All things considered, the e-learning software is easy to use;
2. The e-learning software is reliable (i.e. does not contain bugs or errors);
3. The learning content in the e-learning software was represented in a clear and understandable way;
4. The various instructions and prompt messages are understandable;
5. The graphical parts (symbols, logos, diagrams, pictures and illustrations etc.) of the e-learning software are meaningful;
6. The e-learning software gave accurate feedback in response to my interactions;
7. The navigation and program controls of the e-learning software are logically arranged and consistent and
8. It is easy to use the navigation and program controls of the e-learning software.

The frequency distributions for the above responses are represented in the histograms in Figure 31 to Figure 38.

	N	Min	Max	Median	Mean	Std. Deviation	Frequency Distribution
4 A) All things considered, the e-learning software is easy to use.	47	1	5	4.00	3.66	0.89	Refer to Figure 31
4A) Outliers removed	46	2	5	4.00	3.72	0.80	
4 J) The e-learning software is reliable (i.e. does not contain bugs or errors).	46	1	5	4.00	3.35	1.18	Refer to Figure 32
6 A) The learning content in the e-learning software was represented in a clear and understandable way.	44	1	5	4.00	3.57	1.02	Refer to Figure 33
6 A) Outliers Removed	42	2	5	4.00	3.69	0.87	
4 K) The various instructions and prompt messages are understandable.	47	1	5	4.00	3.66	0.92	Refer to Figure 34
4 K) Outliers Removed	45	2	5	4.00	3.78	0.74	
4 C) The graphical parts (symbols, logos, diagrams, pictures and illustrations etc.) of the e-learning software are meaningful.	47	1	5	4.00	3.53	1.04	Refer to Figure 35
4 C) Outliers Removed	45	2	5	4.00	3.64	0.91	
4 I) The e-learning software gave accurate feedback in response to my interactions.	44	1	5	4.00	3.48	1.05	Refer to Figure 36
4 I) Outliers Removed	41	2	5	4.00	3.66	0.83	
4 D) The navigation and program controls of the e-learning software are logically arranged and consistent.	47	1	5	4.00	3.57	0.88	Refer to Figure 37
4 D) Outliers Removed	46	2	5	4.00	3.63	0.80	
4 E) It is easy to use the navigation and program controls of the e-learning software.	47	1	5	4.00	3.60	1.01	Refer to Figure 38
4 E) Outliers Removed	45	2	5	4.00	3.71	0.87	

Table 48: Phase 3 - Descriptive statistics for usability results

As detailed in Table 48, Figure 31 reflects a distribution (N=47) that is not normal, not skewed and is kurtosis static, where the average student response (Mdn = 4, M=3.66, SD=0.89) **agrees (4)** with the statement "*All things considered, the E-Learning software is easy to use*."

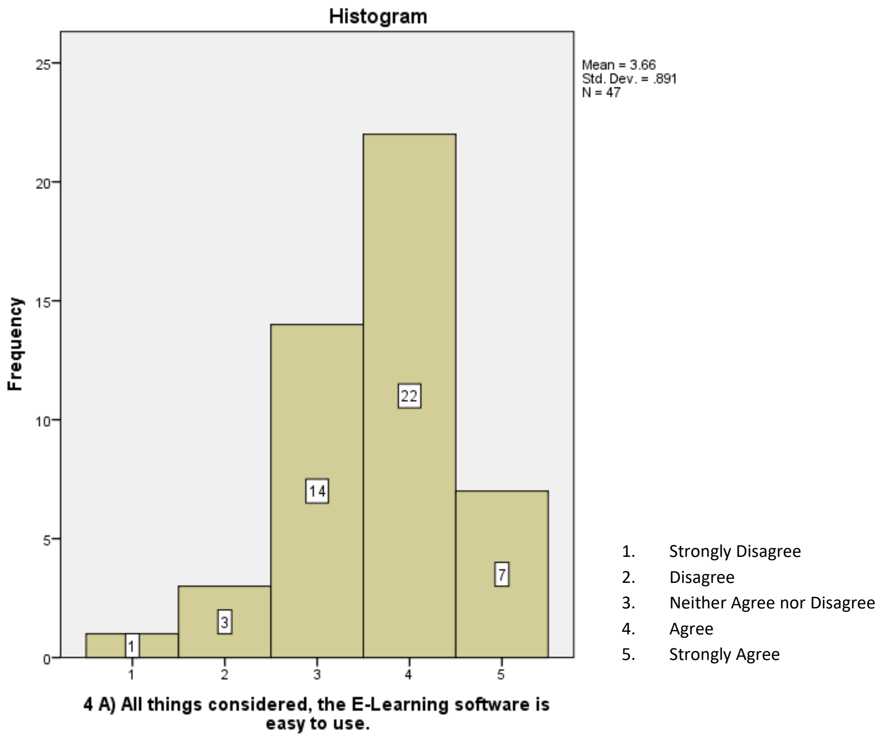


Figure 31: Phase 3 - All things considered, the e-learning software is easy to use.

As detailed in Table 48, Figure 32 reflects a distribution (N=46) that is not normal, not skewed and is kurtosis static, where the average student response (Mdn = 4, M=3.35, SD=1.18) **agrees (4)** with the statement "*The E-Learning software is reliable (i.e. does not contain bugs or errors)*."

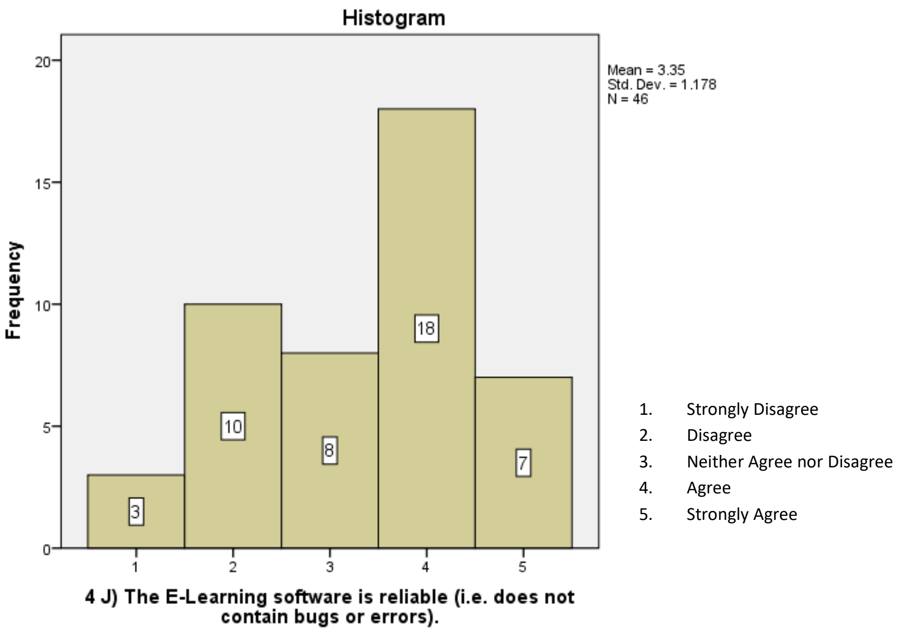


Figure 32: Phase 3 - The e-learning software is reliable (i.e. does not contain bugs or errors).

As detailed in Table 48, Figure 33 reflects a distribution (N=44) that is not normal, not skewed and is kurtosis static, where the average student response (Mdn = 4, M=3.57, SD=1.02) **agrees (4)** with the statement "*The learning content in the E-Learning software was represented in a clear and understandable way.*"

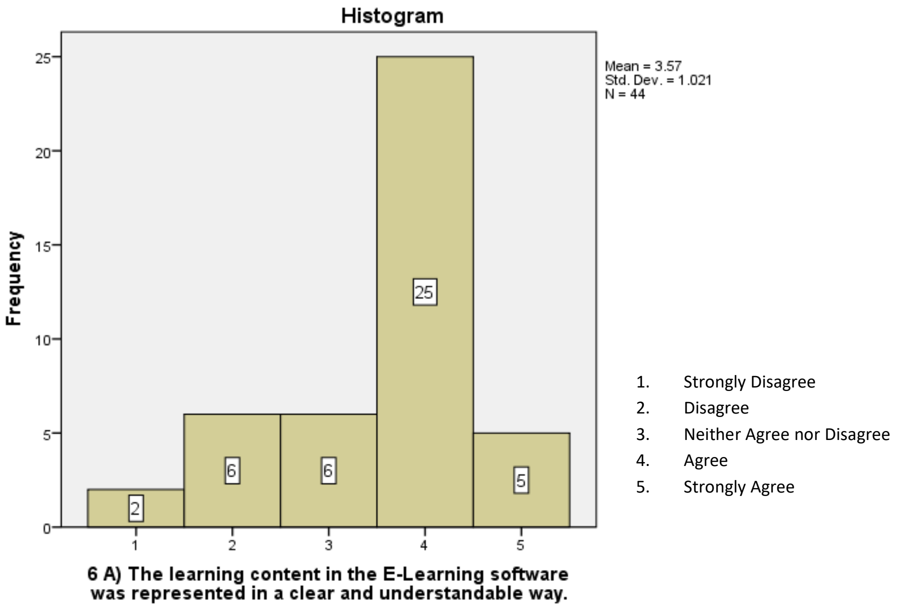


Figure 33: Phase 3- The learning content in the e-learning software was represented in a clear and understandable way.

As detailed in Table 48, Figure 34 reflects a distribution (N=47) that is not normal, is negatively skewed and is leptokurtic, where the average student response (Mdn = 4, M=3.66, SD=0.92) **agrees (4)** with the statement "*The various instructions and prompt messages are understandable*."

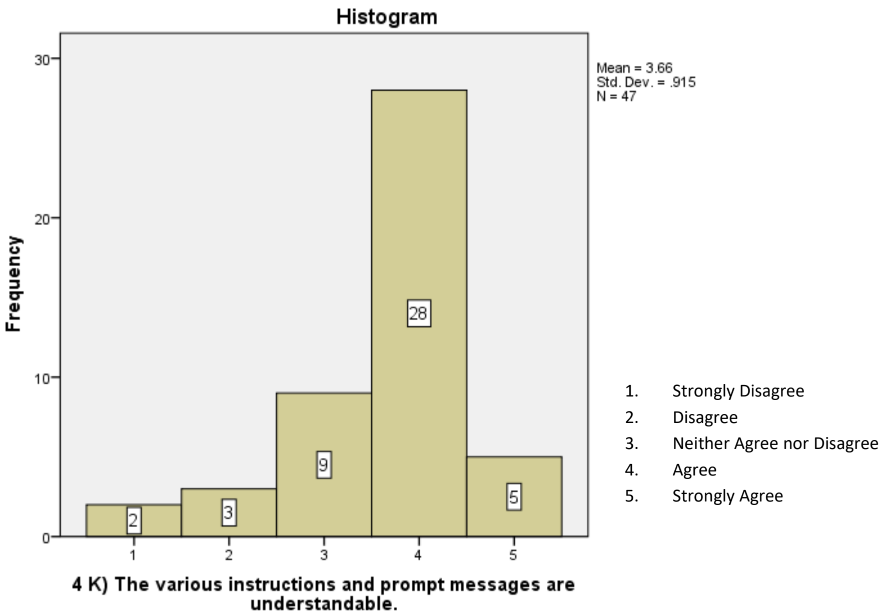


Figure 34: Phase 3- The various instructions and prompt messages are understandable.

As detailed in Table 48, Figure 35 reflects a distribution (N=47) that is not normal, not skewed and is kurtosis static, where the average student response (Mdn = 4, M=3.53, SD=1.04) **agrees (4)** with the statement "*The graphical parts (symbols, logos, diagrams, pictures and illustrations etc.) of the E-Learning software are meaningful*."

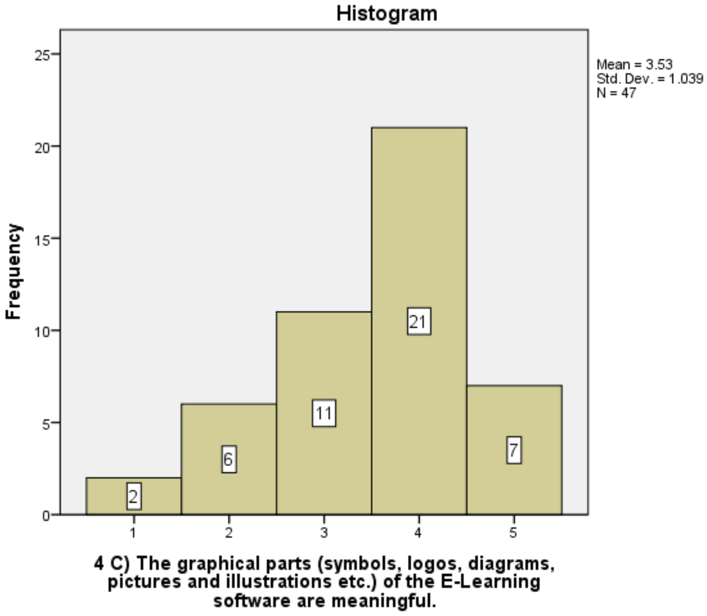
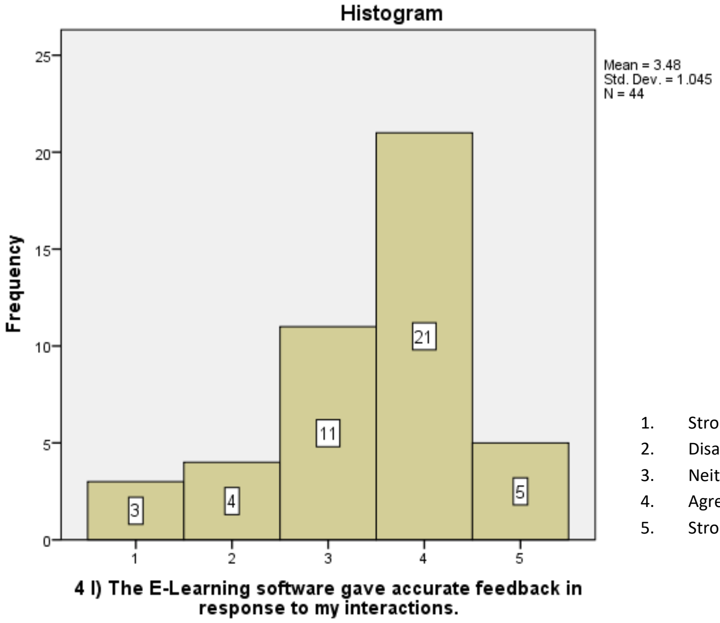


Figure 35: Phase 3 - The graphical parts (symbols, logos, diagrams, pictures and illustrations etc.) of the e-learning software are meaningful.

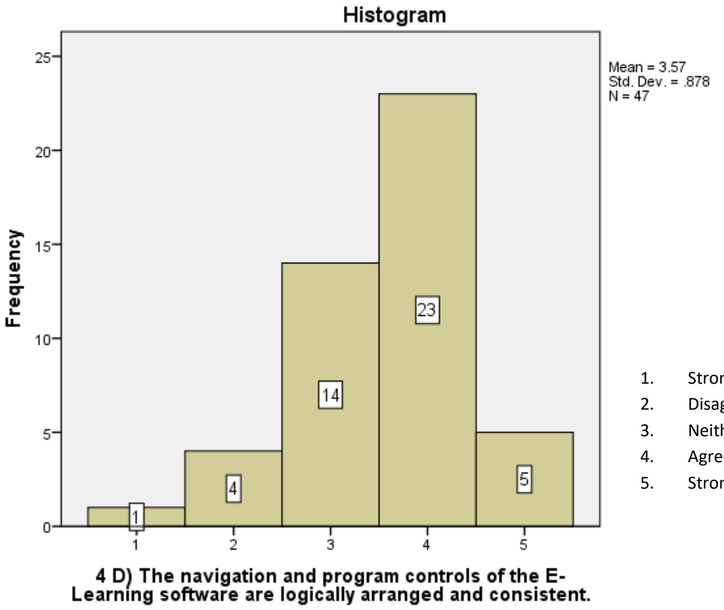
As detailed in Table 48, Figure 36 reflects a distribution (N=44) that is not normal, is negatively skewed and is kurtosis static, where the average student response (Mdn = 4, M=3.48, SD=1.05) **agrees (4)** with the statement "*The E-Learning software gave accurate feedback in response to my interactions*."



1. Strongly Disagree
2. Disagree
3. Neither Agree nor Disagree
4. Agree
5. Strongly Agree

Figure 36: Phase 3 - The e-learning software gave accurate feedback in response to my interactions.

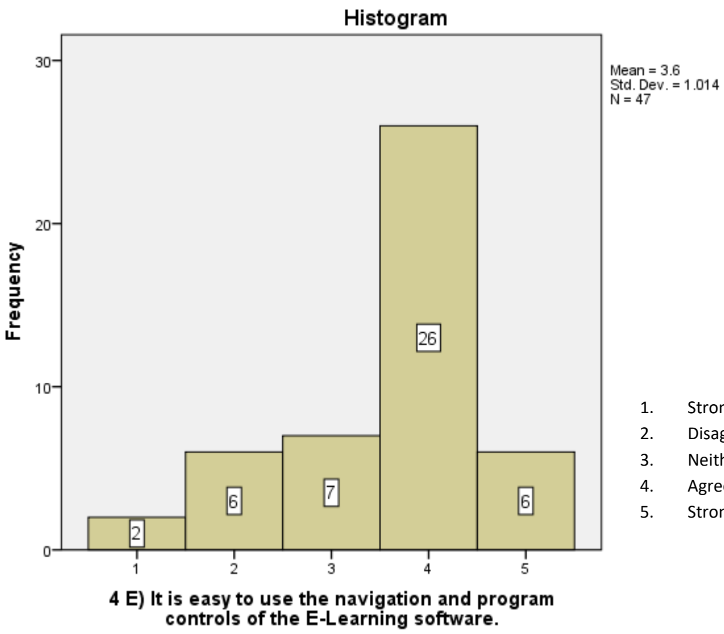
As detailed in Table 48, Figure 37 reflects a distribution (N=47) that is not normal, not skewed and is kurtosis static, where the average student response (Mdn = 4, M=3.57, SD=0.88) **agrees (4)** with the statement "*The navigation and program controls of the E-Learning software are logically arranged and consistent*."



1. Strongly Disagree
2. Disagree
3. Neither Agree nor Disagree
4. Agree
5. Strongly Agree

Figure 37: Phase 3 - The navigation and program controls of the e-learning software are logically arranged and consistent.

As detailed in Table 48, Figure 38 reflects a distribution (N=47) that is not normal, is negatively skewed and is kurtosis static, where the average student response (Mdn = 4, M=3.6, SD=1.01) **agrees (4)** with the statement "*It is easy to use the navigation and program controls of the E-Learning software*."



1. Strongly Disagree
2. Disagree
3. Neither Agree nor Disagree
4. Agree
5. Strongly Agree

Figure 38: Phase 3- It is easy to use the navigation and program controls of the e-learning software.

However, the student participants did raise some usability concerns; with reference to Table 49, the median student response showed **neither agreement nor disagreement (3)** with the following statements:

1. Sometimes I felt that I didn't quite understand what the e-learning software was doing.
2. I found errors (bugs) in the e-learning software that were difficult to recover from.
3. The e-learning software felt speedy and responsive to my interactions.

The frequency distributions for the above responses are represented in the histograms in Figure 39 to Figure 41.

	N	Min	Max	Median	Mean	Std. Deviation	Frequency Distribution
4 F) Sometimes I felt that I didn't quite understand what the e-learning software was doing.	47	1	5	3.00	3.11	1.15	Refer to Figure 39
4 G) I found errors (bugs) in the e-learning software that were difficult to recover from.	47	1	5	3.00	2.74	1.24	Refer to Figure 40
4 H) The e-learning software felt speedy and responsive to my interactions.	44	1	5	3.00	3.07	1.17	Refer to Figure 41

Table 49: Phase 3 - Descriptive Statistics for mixed usability responses

As detailed in Table 49, Figure 39 reflects a distribution (N=47) that is not normal, not skewed and is kurtosis static, where the average student response (Mdn = 3, M=3.11, SD=1.15) **neither agree nor disagree (3)** with the statement *"Sometimes I felt that I didn't quite understand what the E-Learning software was doing*."

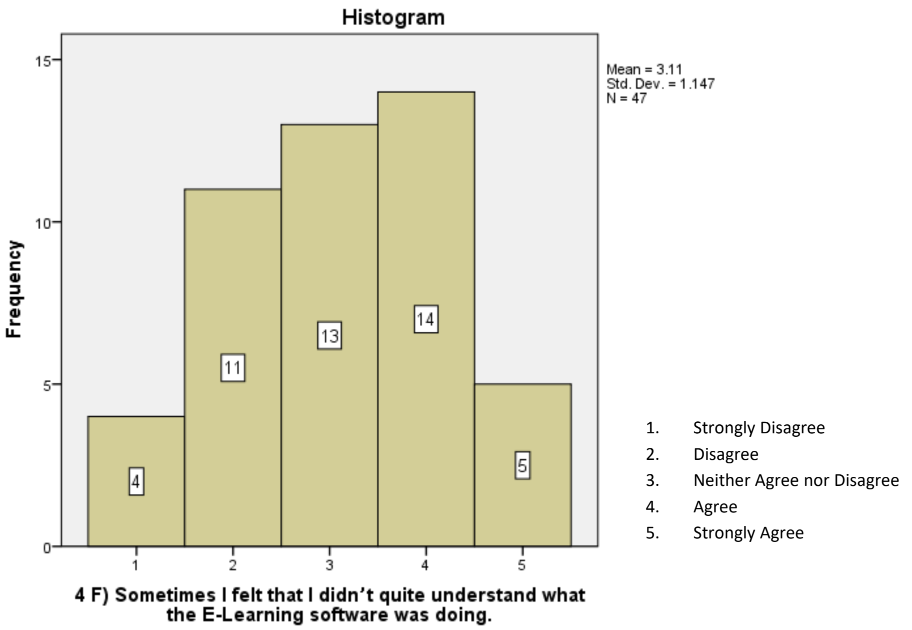


Figure 39: Phase 3- Sometimes I felt that I didn't quite understand what the e-learning software was doing.

As detailed in Table 49, Figure 40 reflects a distribution (N=47) that is not normal, not skewed and is kurtosis static, where the average student response (Mdn = 3, M=2.74, SD=1.24) **neither agree nor**

disagree (3) with the statement *"I found errors (bugs) in the E-Learning software that were difficult to recover from*."

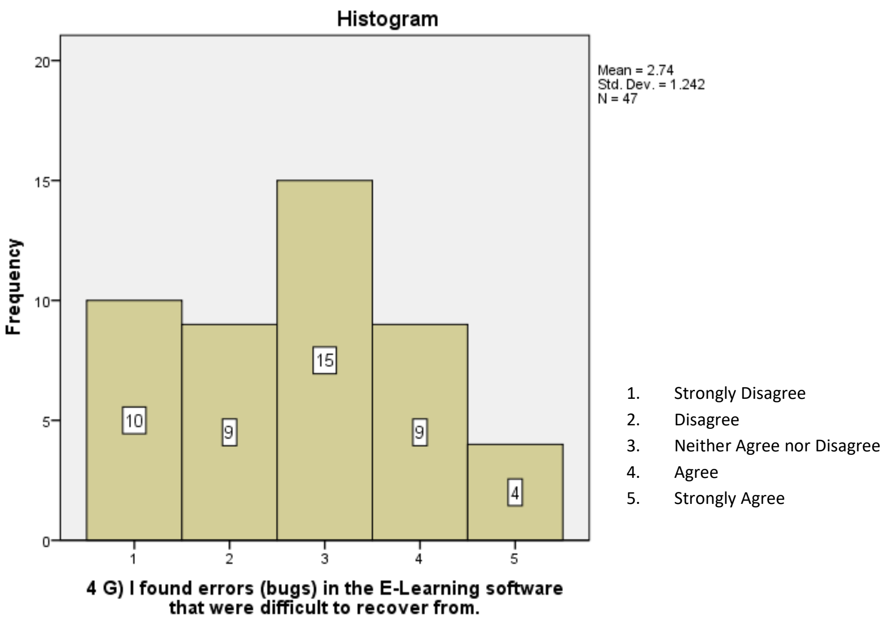


Figure 40: Phase 3 - I found errors (bugs) in the e-learning software that were difficult to recover from.

As detailed in Table 49, Figure 41 reflects a distribution (N=44) that is not normal, not skewed and is kurtosis static, where the average student response (Mdn = 3, M=3.07, SD=1.17) **neither agree nor disagree (3)** with the statement "*The E-Learning software felt speedy and responsive to my interactions*."

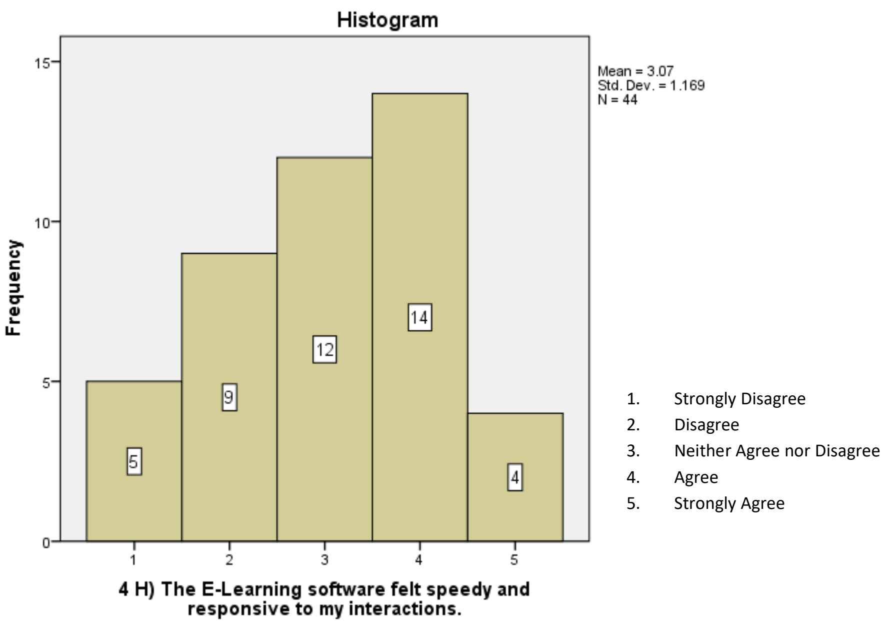


Figure 41: Phase 3- The e-learning software felt speedy and responsive to my interactions.

From 47 student participants, 14 offered additional comments relating to their usability feedback; the following are a representative subset:

"At some points entering and checking an answer made me unable to answer the next questions affecting my score." [P3Student63]

“I can’t open the course on my mac or phones.” [P3Student12]

“the level 2 didn't work for me at first and it lags considerably when I try to advance through its stages.” [P3Student2]

“errors and bugs” [P3Student35]

“Sometimes the program stutters and you have to restart” [P3Student10]

“When you get most of the questions right in the e-learning software and you still get a low mark.” [P3Student8]

“It crashes and you get 0%.” [P3Student23]

One recurring theme, mentioned by five students, was the marking and a perceived inconsistency between the marking on the quiz questions and the final quiz result for each level. This was also recounted by the teacher from School1 who commented on this issue during the debrief session.

6.6.3 Response on the Educational Components used in the E-learning

The student participants gave broadly positive feedback on the impact the different educational components had on their perceived understanding. With reference to Table 50, the median student response showed **agreement** (4) with the following statements:

- The text material in the e-learning software helped me understand the subject matter.
- The videos in the e-learning software helped me understand the subject matter.
- The visual material in the e-learning software helped me understand the subject matter.
- The collaborative activities (forum discussions, group or pair work) helped me understand the subject matter.
- The practice activities (problem-solving) in the e-learning software helped me understand the subject matter.
- The quiz questions (assessment activities) in the e-learning software helped me understand the subject matter.
- The *“extend your knowledge”* learning material in the e-learning software helped me understand the subject matter.

The frequency distributions for the above responses are represented in the histograms in Figure 42 to Figure 48.

	N	Min	Max	Median	Mean	Std. Deviation	Frequency Distribution
6 H) The text material in the e-learning software helped me understand the subject matter.	44	1	5	4.00	3.61	1.02	Refer to Figure 42
6 H) Outliers Removed	43	2	5	4.00	3.67	0.94	
6 K) The videos in the e-learning software helped me understand the subject matter.	44	1	5	4.00	3.50	1.11	Refer to Figure 43
6 K) Outliers Removed	41	2	5	4.00	3.68	0.91	
6 F) The visual material in the e-learning software helped me understand the subject matter.	45	1	5	4.00	3.64	1.09	Refer to Figure 44
6 F) Outliers Removed	43	2	5	4.00	3.77	0.95	
6 I) The collaborative activities (forum discussions, group or pair work) helped me understand the subject matter.	45	1	5	4.00	3.44	1.12	Refer to Figure 45
6 I) Outliers Removed	41	2	5	4.00	3.68	0.85	
6 D) The practice activities (problem-solving) in the e-learning software helped me understand the subject matter.	45	1	5	4.00	3.58	0.99	Refer to Figure 46
6 D) Outliers Removed	43	2	5	4.00	3.70	0.83	
6 E) The quiz questions (assessment activities) in the e-learning software helped me understand the subject matter.	45	1	5	4.00	3.67	1.15	Refer to Figure 47
6 E) Outliers Removed	41	2	5	4.00	3.93	0.82	
6 J) The “extend your knowledge” learning material in the e-learning software helped me understand the subject matter.	45	1	5	4.00	3.33	1.13	Refer to Figure 48
6 J) Outliers Removed	40	2	5	4.00	3.63	0.81	

Table 50: Phase 3 - The impact of the different educational components on perceived understanding

As detailed in Table 50, Figure 42 reflects a distribution (N=44) that is not normal, not skewed and is kurtosis static, where the average student response (Mdn = 4, M=3.61, SD=1.02) **agrees (4)** with the statement "*The text material in the E-Learning software helped me understand the subject matter*."

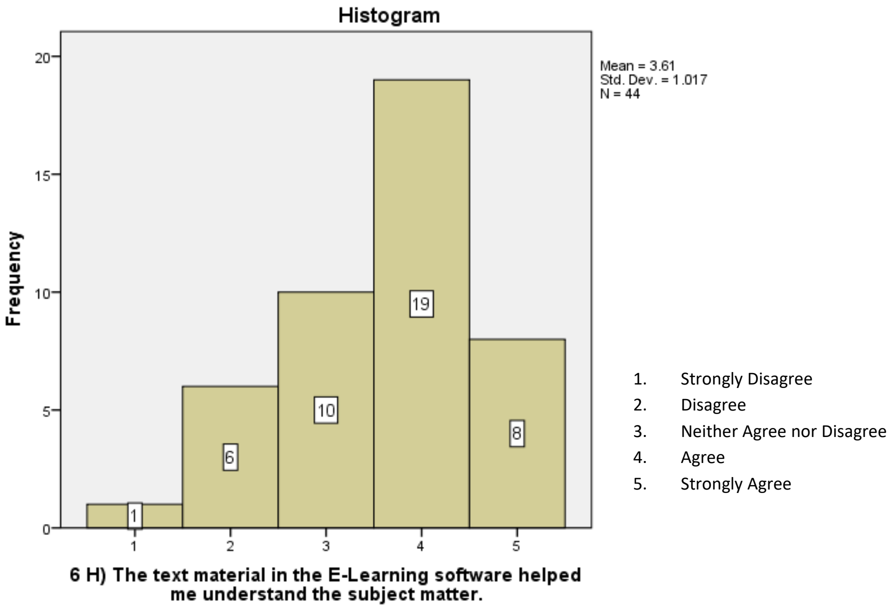


Figure 42: Phase 3 - The text material in the e-learning software helped me understand the subject matter.

As detailed in Table 50, Figure 43 reflects a distribution (N=44) that is not normal, negatively skewed and is kurtosis static, where the average student response (Mdn = 4, M=3.50, SD=1.11) **agrees (4)** with the statement "*The videos in the E-Learning software helped me understand the subject matter*."

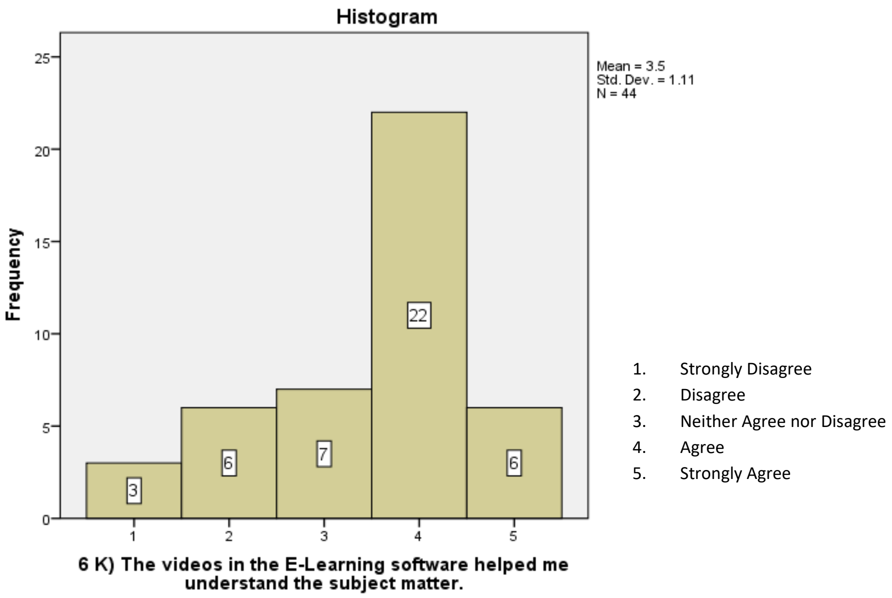


Figure 43: Phase 3 - The videos in the e-learning software helped me understand the subject matter.

As detailed in Table 50, Figure 44 reflects a distribution (N=45) that is not normal, not skewed and is kurtosis static, where the average student response (Mdn = 4, M=3.64, SD=1.09) **agrees (4)** with the statement "*The visual material in the E-Learning software helped me understand the subject matter*."

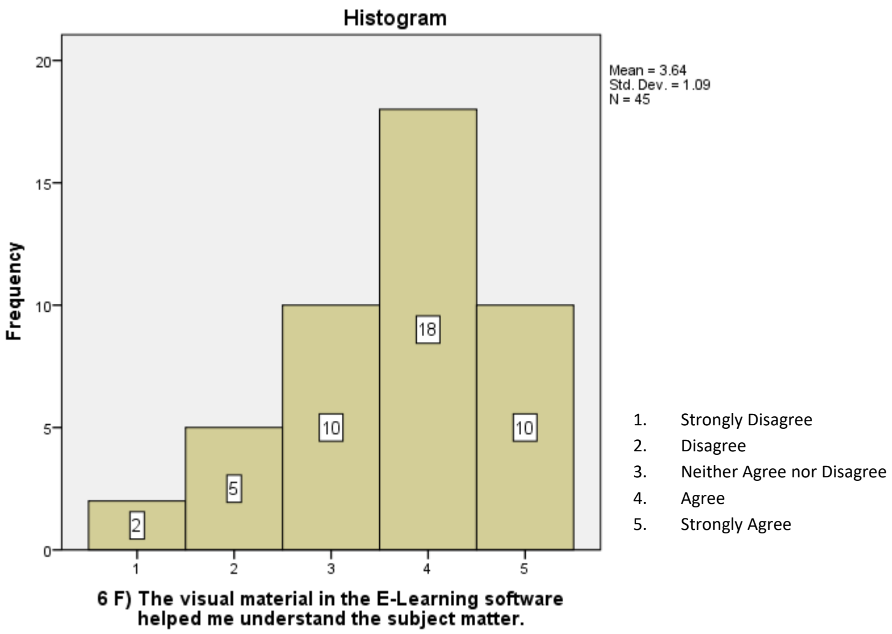


Figure 44: Phase 3 - The visual material in the e-learning software helped me understand the subject matter.

As detailed in Table 50, Figure 45 reflects a distribution (N=45) that is not normal, negatively skewed and is kurtosis static, where the average student response (Mdn = 4, M=3.44, SD=1.12) **agrees (4)** with the statement "The collaborative activities (forum discussions, group or pair work) helped me understand the subject matter."

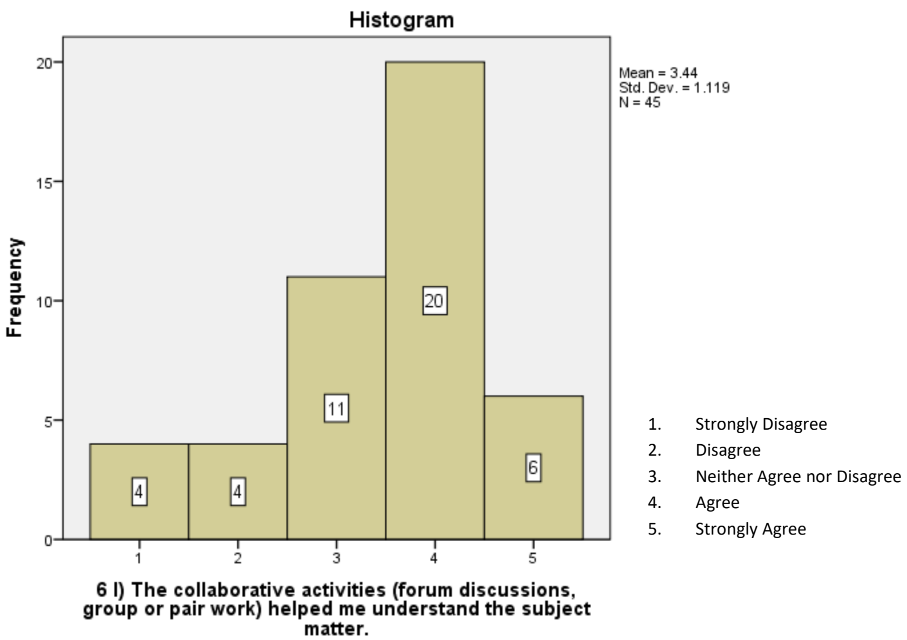


Figure 45: Phase 3 The collaborative activities (forum discussions, group or pair work) helped me understand the subject matter.

As detailed in Table 50, Figure 46 reflects a distribution (N=45) that is not normal, is negatively skewed and is kurtosis static, where the average student response (Mdn = 4, M=3.58, SD=0.99) **agrees (4)** with the statement "*The practice activities (problem solving) in the E-Learning software helped me understand the subject matter*."

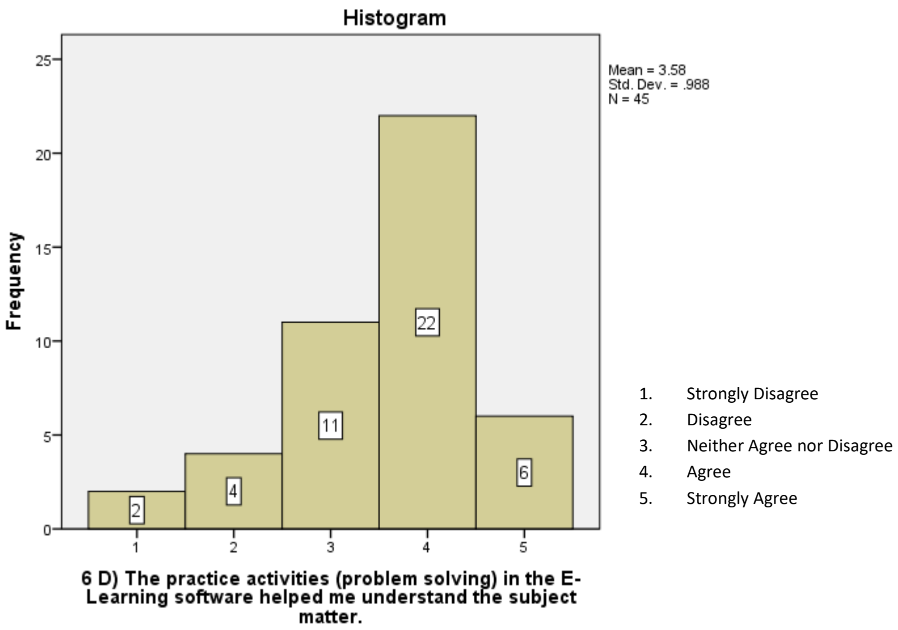


Figure 46: Phase3 - The practice activities (problem-solving) in the e-learning software helped me understand the subject matter.

As detailed in Table 50, Figure 47 reflects a distribution (N=45) that is not normal, negatively skewed and is kurtosis static, where the average student response (Mdn = 4, M=3.67, SD=1.15) **agrees (4)** with the statement "*The quiz questions (assessment activities) in the E-Learning software helped me understand the subject matter.*"

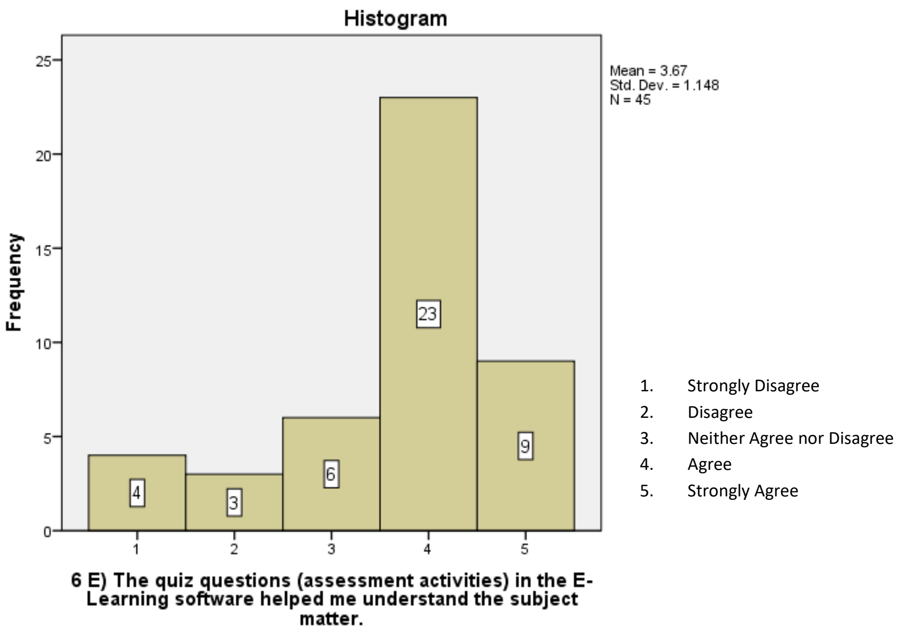


Figure 47: Phase 3- The quiz questions (assessment activities) in the e-learning software helped me understand the subject matter.

As detailed in Table 50, Figure 48 reflects a distribution (N=45) that is not normal, negatively skewed and is kurtosis static, where the average student response (Mdn = 4, M=3.33, SD=1.13) **agrees (4)** with the statement "*The "extend your knowledge" learning material in the E-Learning software helped me understand the subject matter.*"

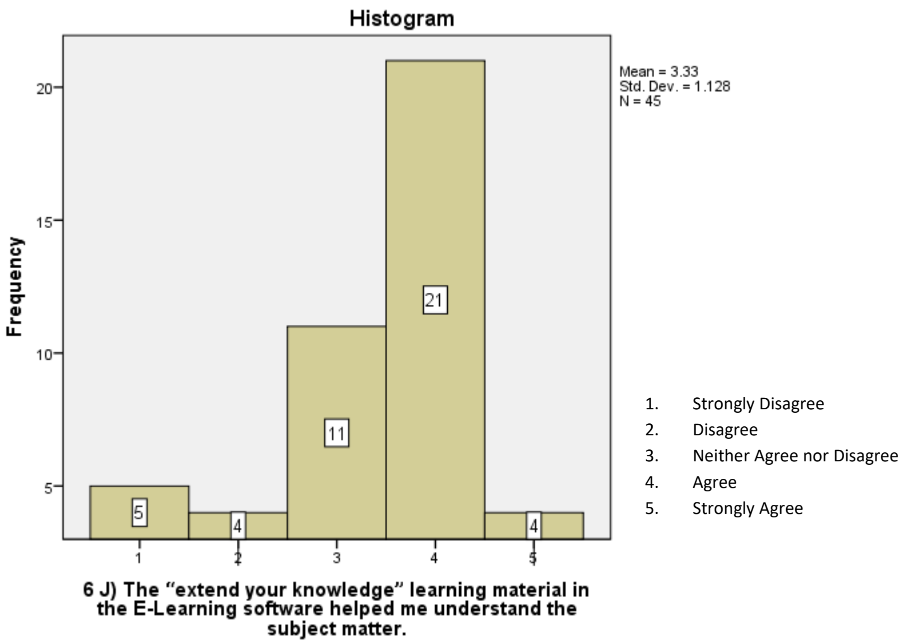


Figure 48: Phase 3 - The 'extend your knowledge' learning material in the e-learning software helped me understand the subject matter.

One exception to the positive feedback, on the impact of the educational components on perceived understanding, is audio content. With N=43, on average (Mdn=3, M=3.09 SD=1.19) the student participants **neither agreed nor disagreed (3)** with the statement *"The audio material in the e-learning software helped me understand the subject matter."* Refer to Figure 49 for the associated frequency distribution, which is not normal, not skewed and is kurtosis static.

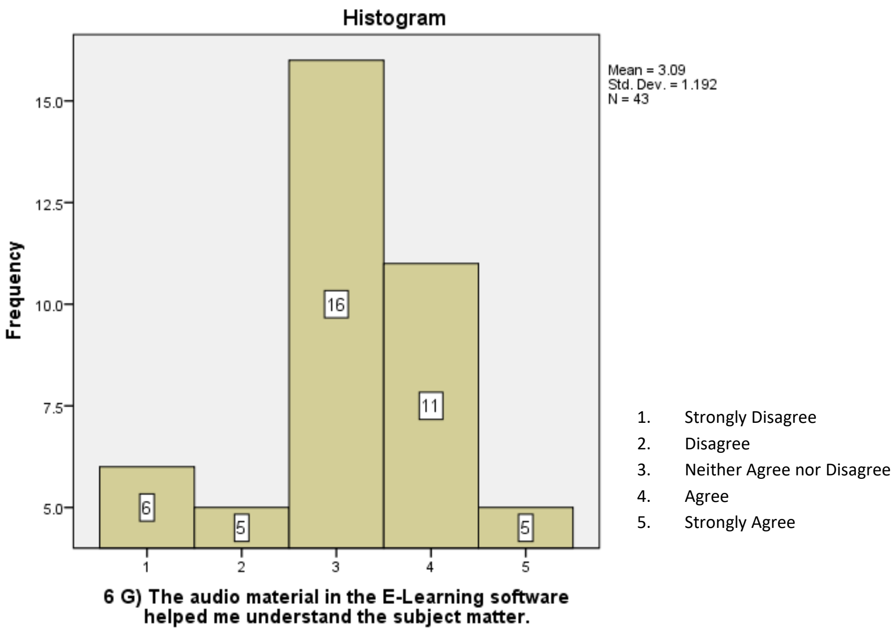


Figure 49: Phase 3 - The audio material in the e-learning software helped me understand the subject matter.

In addition, the student participants ranked the educational components in terms of their perceived benefit to learning and their perceived influence on enthusiasm and interest, where 1 has most benefit / influence and 10 has least benefit / influence. Table 51 shows the rankings for both benefit to learning and influence on enthusiasm and interest. Additionally, it reflects the difference in the rankings between the two. There is consistency between the bottom three rankings; however, there is a mirror effect where the top three rankings for learning benefit are ranked lower in influence on interest and enthusiasm, and the middle four rankings are ranked higher in terms of influence on interest and enthusiasm.

Perceived Benefit to Learning			Perceived Influence on Interest and Enthusiasm		
Educational Component	pct. (%)	Rank	Rank	pct. (%)	Educational Component
Text	8.48%	1	1	7.44%	Games
Video	8.48%	1	2	8.82%	Quizzes
Practice Activities	8.91%	3	3	9.04%	Animations / Simulations
Quizzes	9.58%	4	4	9.26%	Pictures / Photos / Diagrams
Pictures / Photos / Diagrams	9.58%	4	5	9.31%	Video
Animations / Simulations	9.76%	6	6	9.75%	Text
Games	10.06%	7	7	10.96%	Practice Activities
Audio	11.21%	8	8	11.46%	Audio
Collaborative Activities	11.58%	9	9	11.90%	Collaborative Activities
Extended Knowledge	12.36%	10	10	12.07%	Extended Knowledge

Table 51: Phase 3- Educational components impact on perceived learning, and perceived interest and enthusiasm

6.6.4 Response on Perceived Difficulty

Based on the following Likert scale: 1 Too Easy, 2 A Little Easy, 3 At the Right Level, 4 A Little Difficult and 5 Too Difficult, the student participants gave feedback on the perceived difficulty of the educational content in the prototype e-learning software.

With reference to Table 52, the median student response showed the difficulty level of the following educational areas to be **at the right level (3):**

1. Learning material
2. Practice activities (problem-solving)
3. Quiz questions (assessment activities)

The frequency distributions for the above responses are represented in the histograms in Figure 50 to Figure 52.

	N	Min	Max	Median	Mean	Std. Deviation	Frequency Distribution
8 A) Overall, at what difficulty level do you believe the learning material represented in the e-learning software was at?	40	2	5	3.00	3.35	0.62	Refer to Figure 50
8 B) Overall, at what difficulty level do you believe the practice activities (problem-solving) were at?	40	1	5	3.00	3.05	0.90	Refer to Figure 51
8 C) Overall, at what difficulty level do you believe the quiz questions (assessment activities) were at?	40	2	5	3.00	3.15	0.86	Refer to Figure 52

Table 52: Phase 3- Difficulty level of the educational content in the prototype e-learning software

As detailed in Table 52, Figure 50 reflects a distribution (N=40) that is not normal, not skewed and is kurtosis static, where the average student response (Mdn = 3, M=3.35, SD=0.62) asses the learning material represented in the e-learning software to be **at the right level (3)**.

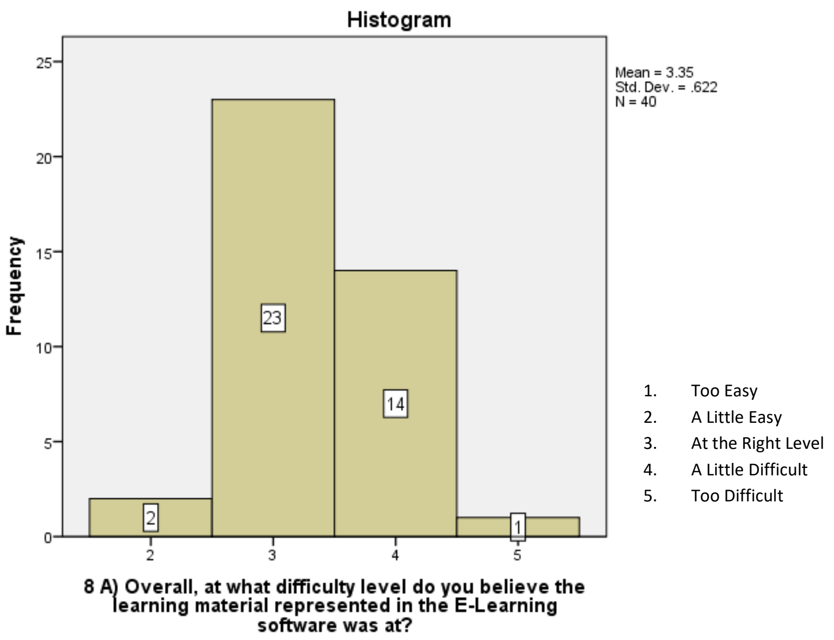


Figure 50: Phase 3- Overall, at what difficulty level do you believe the learning material represented in the e-learning software was at?

As detailed in Table 52, Figure 51 reflects a distribution (N=40) that is not normal, not skewed and is kurtosis static, where the average student response (Mdn = 3, M=3.05, SD=0.90) asses the difficulty of practice activities (problem solving) to be **at the right level (3)**.

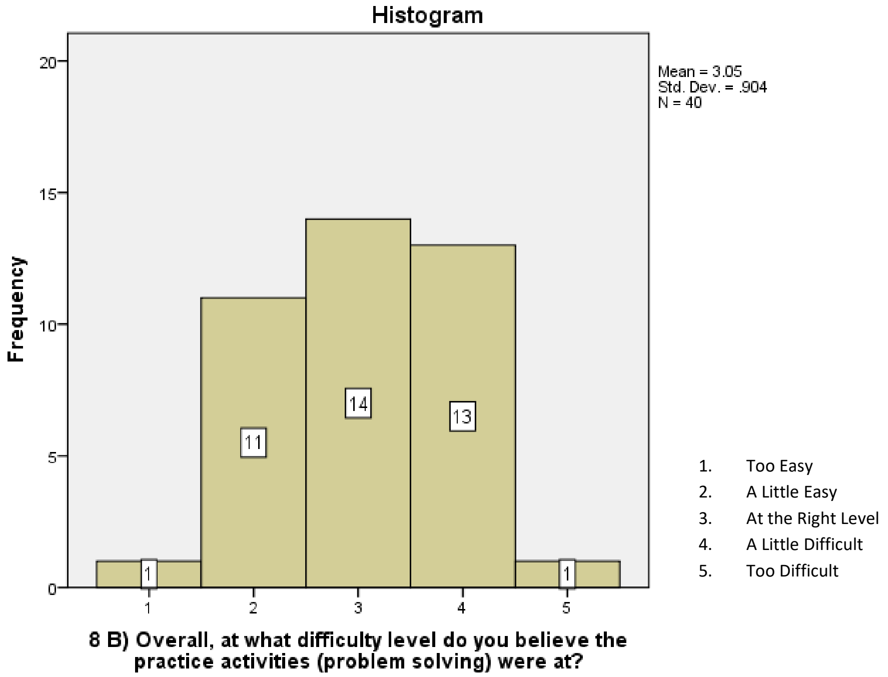


Figure 51: Phase 3- Overall, at what difficulty level do you believe the practice activities (problem-solving) were at?

As detailed in Table 52, Figure 52 reflects a distribution (N=40) that is not normal, not skewed and is kurtosis static, where the average student response (Mdn = 3, M=3.15, SD=0.86) asses the difficulty of quiz questions (assessment activities) to be **at the right level (3)**.

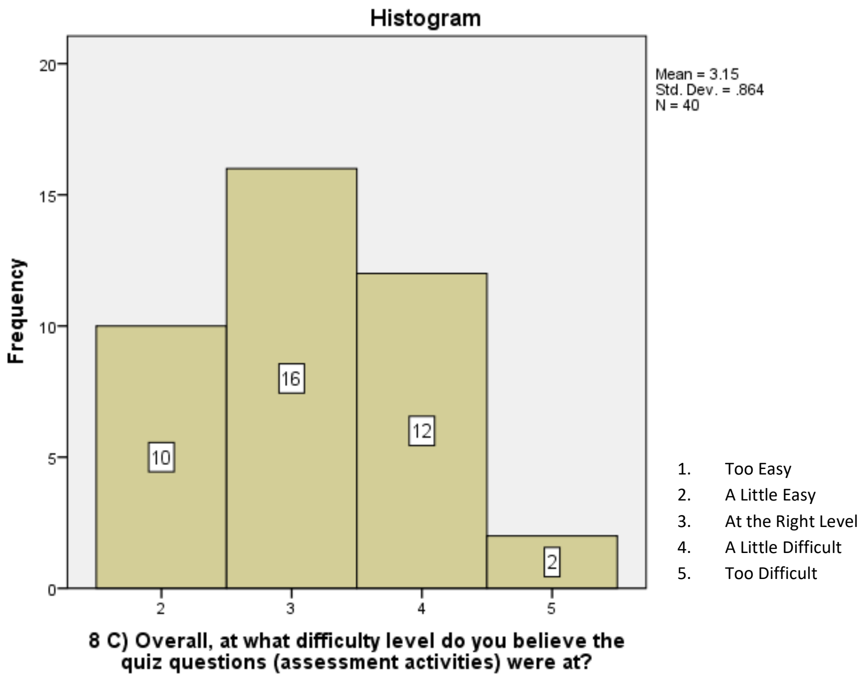


Figure 52: Phase 3 - Overall, at what difficulty level do you believe the quiz questions (assessment activities) were at?

Although the student average response indicates that the e-learning software is at the right difficulty level; the students remain non-committal on whether they needed to supplement the e-learning software with additional learning material, or whether they felt the need to ask their teacher for support. With reference to Table 53, the median student response showed that they **neither agreed nor disagreed (3)** with the following statements:

1. I supplemented, or needed to supplement, the learning material in the e-learning software with further textbook reading.
2. I asked, or wanted to ask, my teacher for support in understanding the learning material in the e-learning software.

	N	Min	Max	Median	Mean	Std. Deviation	Frequency Distribution
6 L) I supplemented, or needed to supplement, the learning material in the e-learning software with further textbook reading.	45	1	5	3.00	3.13	1.06	Refer to Figure 53
6 L) Outliers Removed	40	2	5	3.00	3.40	0.78	
6 M) I asked, or wanted to ask, my teacher for support in understanding the learning material in the e-learning software.	45	1	5	3.00	3.31	1.15	Refer to Figure 54
6 M) Outliers Removed	41	2	5	4.00	3.54	0.93	

Table 53: Phase 3 - Student response on whether they needed to supplement the e-learning software.

As detailed in Table 53, Figure 53 reflects a distribution (N=45) that is not normal, not skewed and is kurtosis static, where the average student response (Mdn = 3, M=3.13, SD=1.06)) **neither agree nor disagree** with the statement "*I supplemented, or needed to supplement, the learning material in the E-Learning software with further textbook reading*."

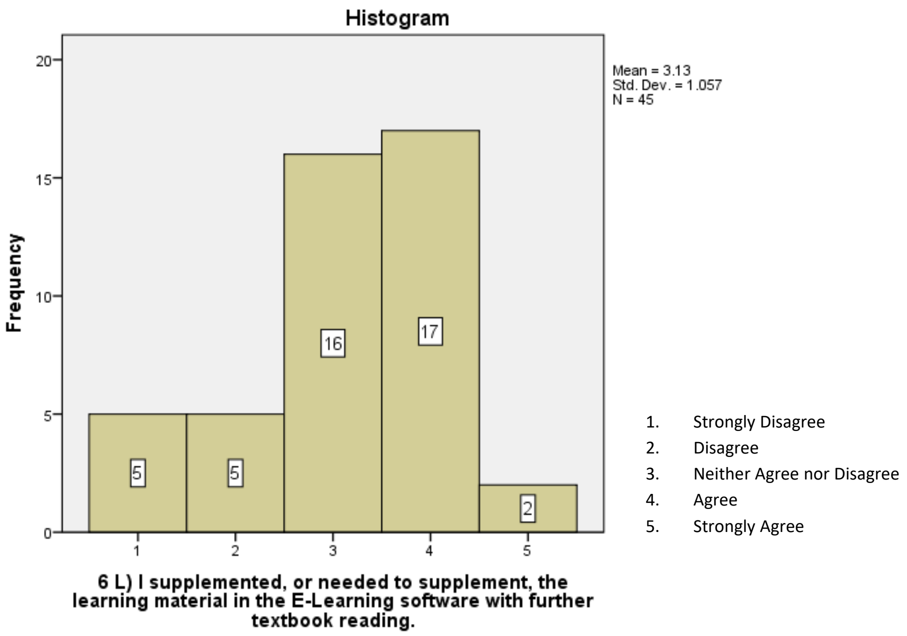


Figure 53: Phase 3 - I supplemented, or needed to supplement, the learning material in the e-learning software with further textbook reading.

As detailed in Table 53, Figure 54 reflects a distribution (N=45) that is not normal, not skewed and is kurtosis static, where the average student response (Mdn = 3, M=3.31, SD=1.15) **neither agrees nor disagrees (3)** with the statement "I asked, or wanted to ask, my teacher for support in understanding the learning material in the E-Learning software. However, It should be noted that the removal of 4 outliers from question 6 M) meant N=41 and the median student response now showed **agreement (4)** with the previous statement.

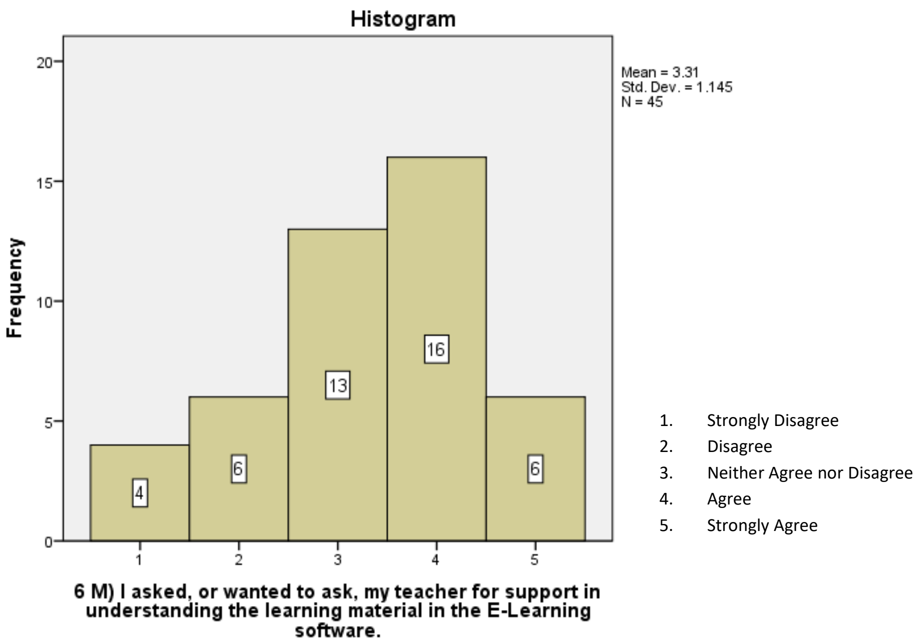
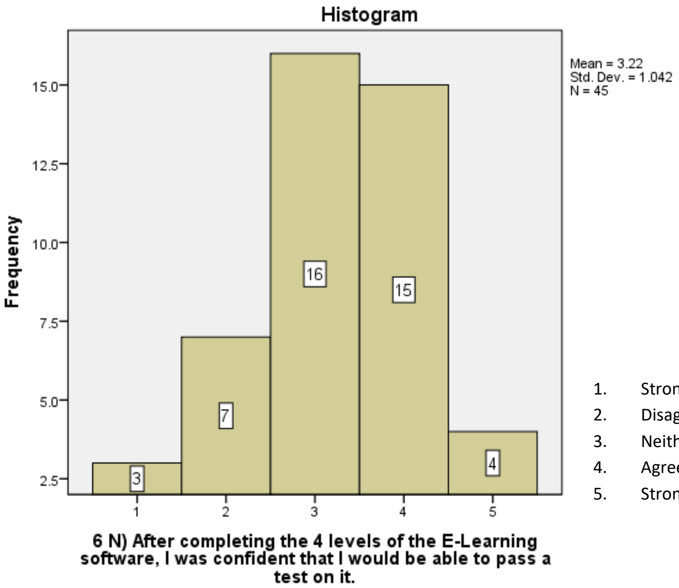


Figure 54: Phase 3 - I asked, or wanted to ask, my teacher for support in understanding the learning material in the e-learning software.

There is potential for concern that 19 of the 45 participants either agreed or strongly agreed with the statement that they supplemented or needed to supplement the learning material in the e-learning software with further textbook reading. This sentiment is reinforced by the feedback that 22 of the 45 respondents asked or wanted to ask their teacher for support in understanding the learning material in the e-learning software.

It should be noted that 13 students confirmed that they did use other educational material between the pre-test and post-test.

The previous two responses give a potential explanation for why, with N=45, on average (Mdn=3, M=3.22 SD=1.04) the student participants **neither agreed nor disagreed (3)** with the statement *"After completing the 4 levels of the e-learning software, I was confident that I would be able to pass a test on it."* Refer to Figure 55 for the frequency distribution of responses, which is not normal, not skewed and kurtosis static.



1. Strongly Disagree
2. Disagree
3. Neither Agree nor Disagree
4. Agree
5. Strongly Agree

Figure 55: Phase 3 - After completing the four levels of the e-learning software, I was confident that I would be able to pass a test on it.

It should be noted though that with the removal of three outliers, N=42 and the mean average (Mdn=3, M=3.38 SD=0.88) increased.

6.6.4.1 Survey Reliability Results

In the Phase 3 survey instrument, alternate form reliability is established by adjusting the wording and reversing the scale for the following question pair:

- 4 A) All things considered, the e-learning software is easy to use, and
- 12 A) Overall, the e-learning software was difficult to use.

With reference to Table 54, a medium effect negative correlation is reflected.

			12 A) Overall, the E-Learning software was difficult to use.
Spearman's rho		Correlation Coefficient	-.35
		Sig. (2-tailed)	.03

	4 A) All things considered, the e-learning software is easy to use.	N	41

Table 54: Phase 3 - Alternate form reliability for survey instrument

Internal consistency is established by assessing two groups of questions using Cronbach's alpha, to identify whether they measure the same underlying concept

- Questions 4A), 4C), 4D), 4E), 4H), 4I) 4J) and 4K) all measure **usability** of the prototype software,
- Questions 8A), 8B) and 8C all measure the **difficulty** of the prototype software.

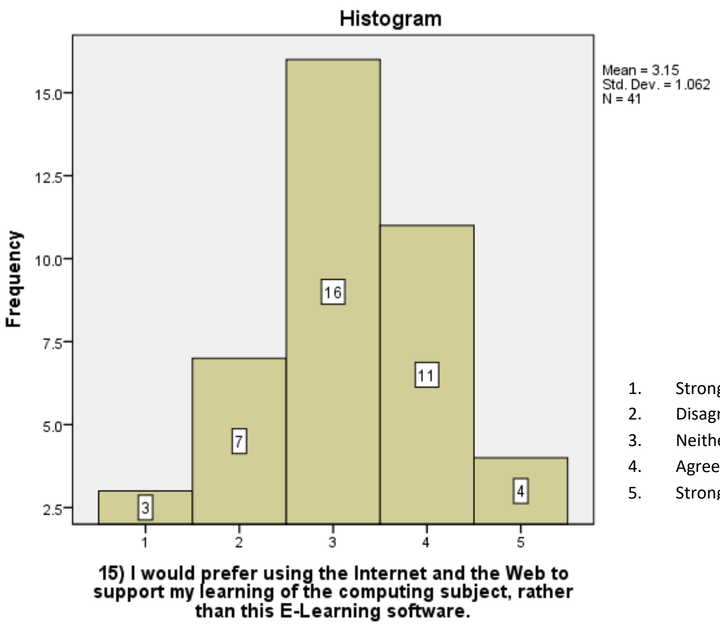
With reference to Table 55, acceptable internal consistency is reflected in both scales (refer to section 6.6.5.2 for a brief discussion on threshold values for Cronbach's alpha).

Scale	Reliability Estimate (Cronbach α)	Items in Scale
E-learning Usability	.74	8
E-learning Difficulty	.66	3

Table 55: Phase 3 - Internal consistency for survey instrument

6.6.5 Motivation and Preferences

The participant response on the impact of the e-learning prototype on motivation is mixed; with N=41, on average (Mdn=3, M=3.15 SD=1.06) the student participants **neither agreed nor disagreed (3)** with the statement *"I would prefer using the Internet and the Web to support my learning of the computing subject rather than this E-Learning software."* Refer to Figure 56 for the frequency distribution, which is not normal, not skewed and kurtosis static.



1. Strongly Disagree
2. Disagree
3. Neither Agree nor Disagree
4. Agree
5. Strongly Agree

Figure 56: Phase 3- I would prefer using the internet and the web to support my learning of the computing subject rather than this e-learning software.

With N=41, on average (Mdn=3, M=3.37 SD=1.18) the student participants **neither agreed nor disagreed (3)** with the statement *"It is more interesting to use the E-Learning software to learn Computing than the textbooks."* Refer to Figure 57 for the frequency distribution, which is not normal, not skewed and kurtosis static. However, has multiple modes in that an equal number of students **neither agreed nor disagreed (3)** and **agreed (4)** with the aforementioned statement.

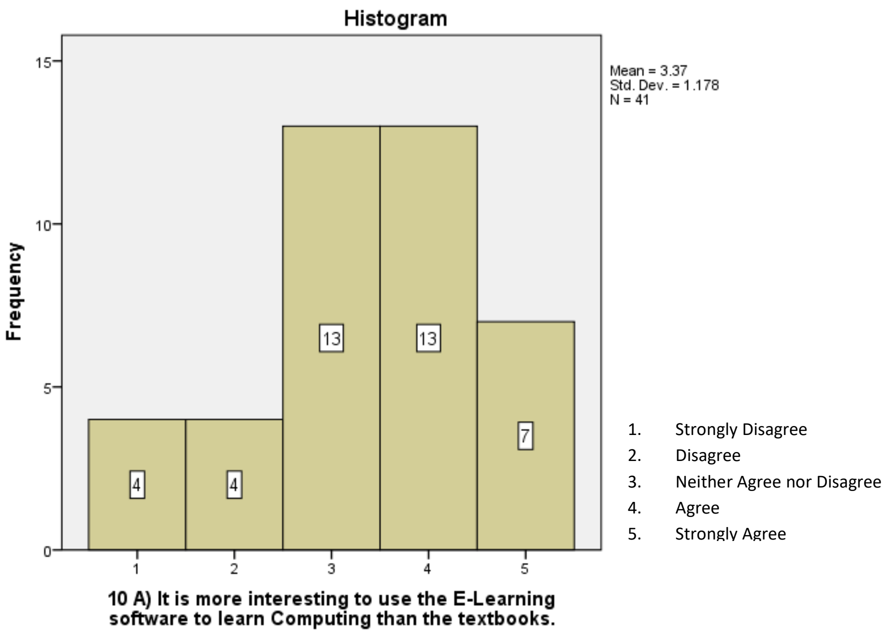


Figure 57: Phase 3- It is more interesting to use the e-learning software to learn computing than the textbooks.

However, with the removal of four outliers, N=37 and now, on average (Mdn=4, M=3.62 SD=0.92), the student participants **agreed (4)** with the statement *"It is more interesting to use the E-Learning software to learn Computing than the textbooks."*

Furthermore, with reference to Table 56, the average student response showed **agreement (4)** with the following statements:

1. I could use the e-learning software for independent study to learn computing.
2. The e-learning software has increased my overall enthusiasm and interest in computing.

	N	Min	Max	Median	Mean	Std. Deviation	Frequency Distribution
10 B) I could use the e-learning software for independent study to learn computing.	41	1	5	4.00	3.54	0.98	Refer to Figure 58
10 B) Outliers Removed	39	2	5	4.00	3.67	0.81	
10 C) The e-learning software has increased my overall enthusiasm and interest in computing.	41	1	5	4.00	3.39	1.05	Refer to Figure 59
10 C) Outliers Removed	37	2	5	4.00	3.65	0.72	

Table 56: Phase 3 - Participant responses on the prototype's effect on overall enthusiasm and interest in computing

As detailed in Table 56, Figure 58 reflects a negatively skewed distribution (N=41) where the average student response (Mdn=4, M=3.54, SD=0.98) **agrees (4)** with the statement "*I could use the E-Learning software for independent study to learn Computing*."

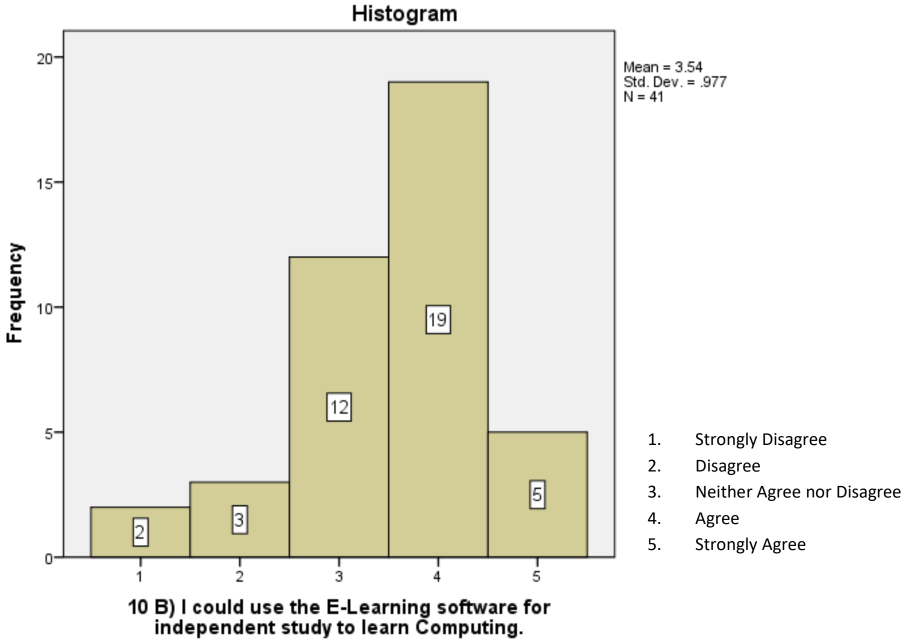


Figure 58: Phase 3 - I could use the e-learning software for independent study to learn computing.

As detailed in Table 56, Figure 59 reflects a negatively skewed distribution (N=41) where the average student response (Mdn=4, M=3.39, SD=1.05) **agrees (4)** with the statement "*The E-Learning software has increased my overall enthusiasm and interest in Computing*."

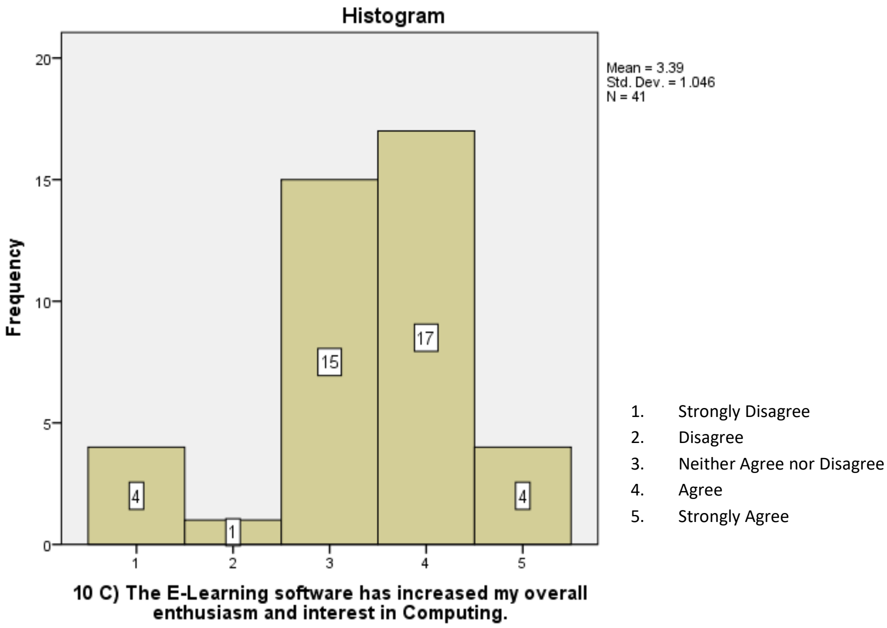


Figure 59: Phase 3- The e-learning software has increased my overall enthusiasm and interest in computing.

6.6.5.1 Instructional Materials Motivation Survey

A more comprehensive view of the participants' level of motivation is provided by Keller's (2006) Instructional Materials Motivation Survey (IMMS), which groups questions according to the motivational areas of attention, relevance, confidence and satisfaction, and measures responses on the following Likert scale: 1 Not True, 2 Slightly True, 3 Moderately True, 4 Mostly True and 5 Very True.

With reference to Table 57, the median student response for the ARCS subcategories ranged between 3.00 and 3.33, which is between **Moderately True (3)** and **Mostly True (4).** These overall weakly positive results for the ARCS subcategories are represented in Figure 60.

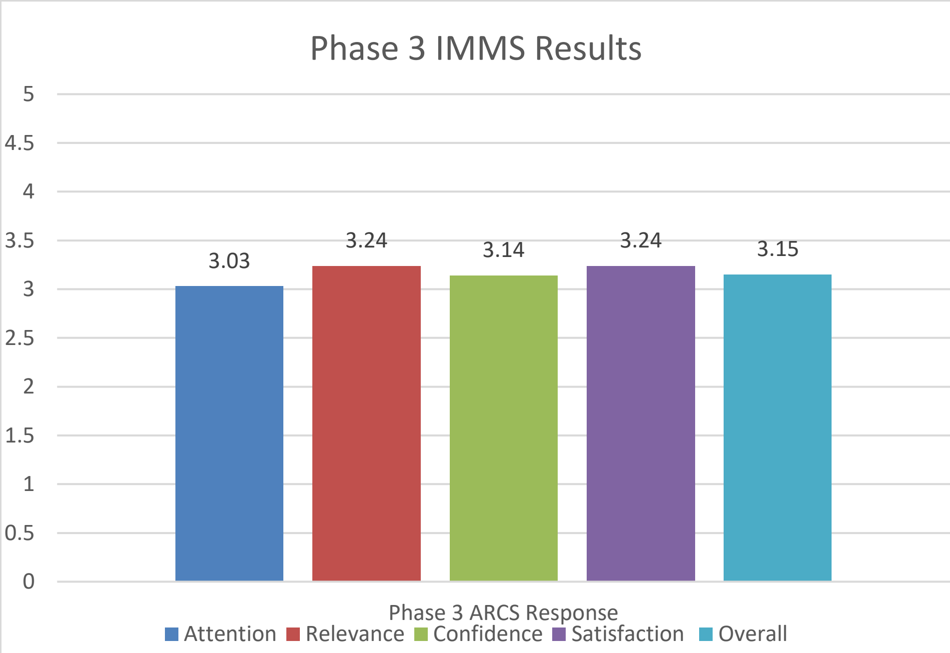


Figure 60: Phase3 - IMMS ARCS summary results (mean)

The frequency distributions for ARCS (IMMS) overall and its subcategories are represented in the histograms in Figure 61 to Figure 65.

	N	Min	Max	Median	Mean	Std. Deviation	Frequency Distribution
Student Attention	42	1.17	4.36	3.00	3.03	0.54	Refer to Figure 61
Outliers Removed	39	2.25	3.67	3.00	3.01	0.36	
Student Relevance	42	1.44	4.75	3.29	3.24	0.71	Refer to Figure 62
Outliers Removed	40	2.00	4.75	3.33	3.33	0.60	
Student Confidence	42	1.67	4.78	3.11	3.14	0.51	Refer to Figure 63
Outliers Removed	40	2.56	4.11	3.11	3.14	0.39	
Student Satisfaction	42	1.00	4.83	3.33	3.24	0.97	Refer to Figure 64
Outliers Removed	39	2.00	4.83	3.33	3.41	0.77	
IMMS Overall	42	1.56	4.56	3.11	3.15	0.56	Refer to Figure 65
Outliers Removed	40	2.00	4.34	3.11	3.15	0.46	

Table 57: Phase 3 - IMMS summary results for Attention, Relevance, Confidence and Satisfaction

As detailed in Table 57, Figure 61 reflects a normal distribution (N=42) where the average student response (Mdn = 3, M=3.03, SD=0.54) is between **moderately true (3)** and **mostly true (4)** for attention.

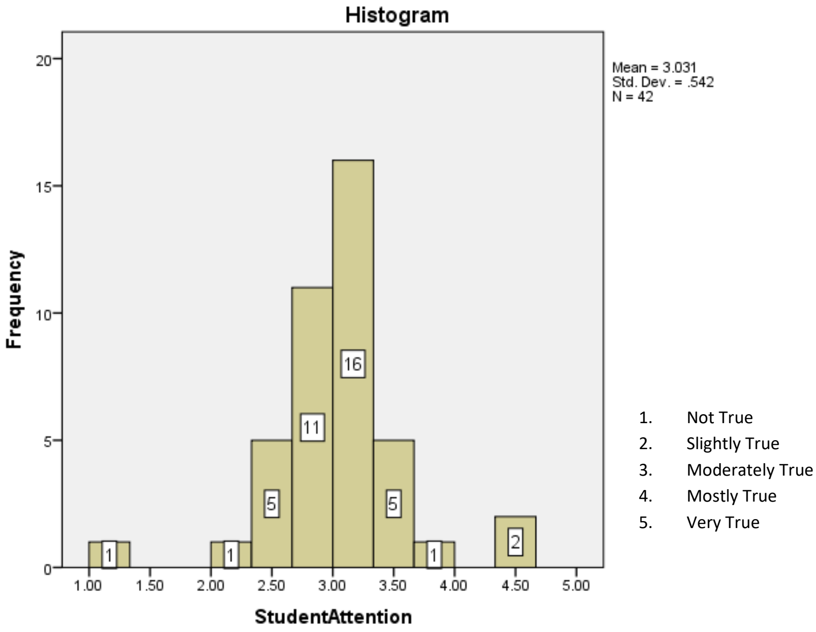


Figure 61: Phase 3 - IMMS Attention frequency distribution

As detailed in Table 57, Figure 62 reflects a normal distribution (N=42) where the average student response (Mdn = 3.29, M=3.24, SD=0.71) is between **moderately true (3)** and **mostly true (4)** for relevance.

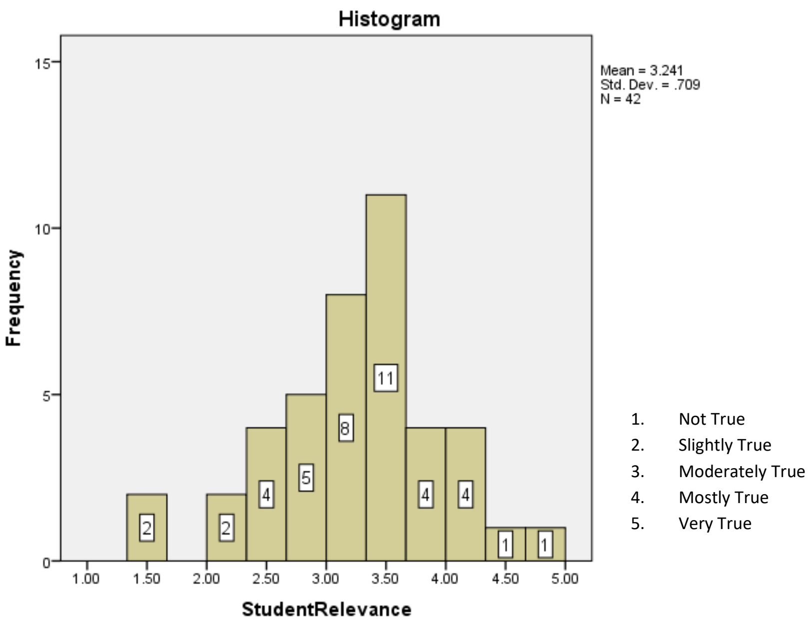


Figure 62: Phase 3 - IMMS Relevance frequency distribution

As detailed in Table 57, Figure 63 reflects a normal distribution (N=42) where the average student response (Mdn = 3.11, M=3.14, SD=0.51) is between **moderately true (3)** and **mostly true (4)** for confidence.

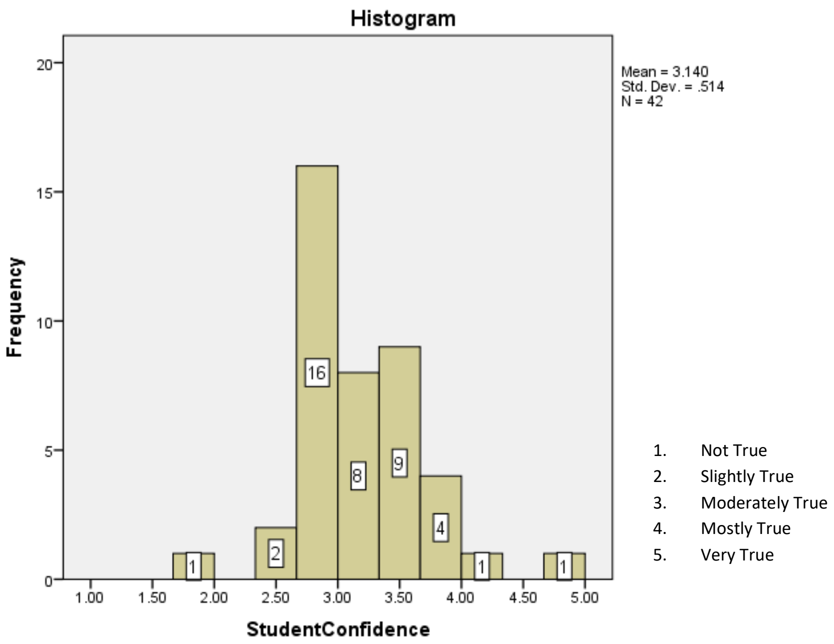


Figure 63: Phase 3 - IMMS Confidence frequency distribution

As detailed in Table 57, Figure 64 reflects a normal distribution (N=42) where the average student response (Mdn = 3.33, M=3.24, SD=0.97) is between **moderately true (3)** and **mostly true (4)** for satisfaction.

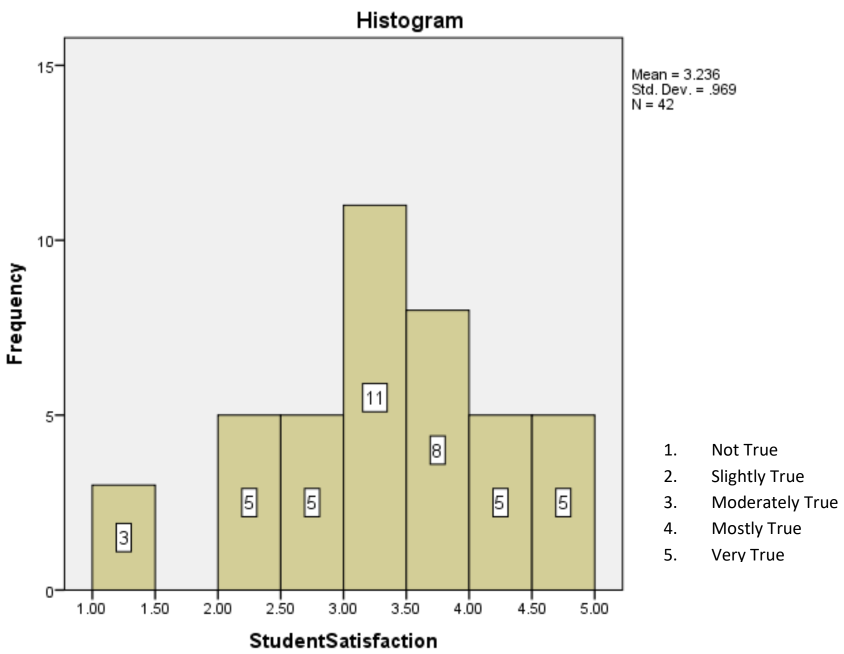
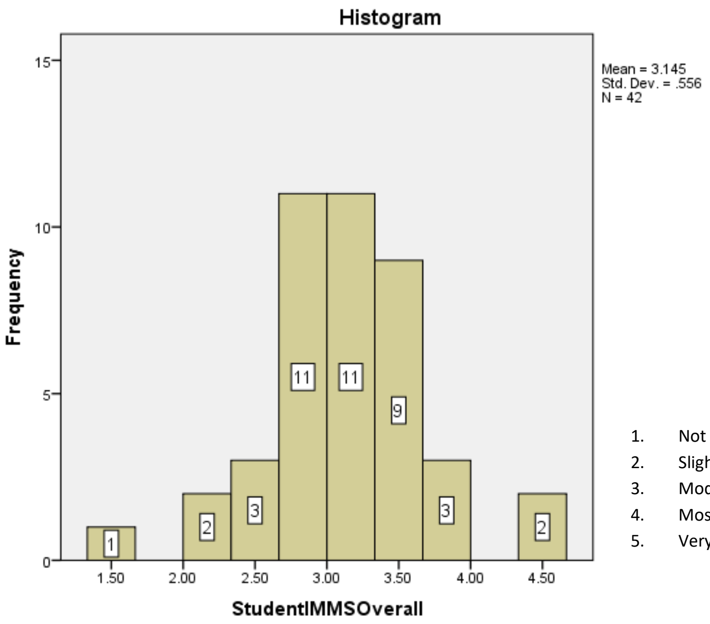


Figure 64: Phase 3 - IMMS Satisfaction frequency distribution

As detailed in Table 57, Figure 65 reflects a normal distribution (N=42) where the average student response (Mdn = 3.11, M=3.15, SD=0.56) is between **moderately true (3)** and **mostly true (4)** for IMMS overall.



1. Not True
2. Slightly True
3. Moderately True
4. Mostly True
5. Very True

Figure 65: Phase 3 - IMMS overall motivation frequency distribution

The mean participant result for Attention and Confidence is comparatively less than both Relevance and Satisfaction. Using the Kolmogorov-Smirnov test, the distributions for Attention, Relevance, Confidence and Satisfaction are confirmed to be normal. With reference to Table 58, paired sample T-Tests were used to compare the ARCS subcategories.

Paired Samples Test

		Paired Differences					t	df	Sig. (2-tailed)
		Mean	Std. Deviation	Std. Error Mean	95% Confidence Interval of the Difference Lower	Upper			
Pair 1	StudentAttention - StudentRelevance	-.21	0.58	0.09	-0.39	-0.03	-2.35	41	.02
Pair 2	StudentAttention - StudentConfidence	-.11	0.35	0.05	-0.22	0.00	-1.99	41	.05
Pair 3	StudentAttention - StudentSatisfaction	-.20	0.80	0.12	-0.45	0.04	-1.66	41	.11
Pair 4	StudentConfidence - StudentRelevance	-.10	0.57	0.09	-0.28	0.08	-1.14	41	.26
Pair 5	StudentConfidence - StudentSatisfaction	-.09	0.84	0.13	-0.36	0.17	-0.74	41	.47
Pair 6	StudentRelevance - StudentSatisfaction	.01	0.57	0.09	-0.17	0.18	0.06	41	.95

Table 58: Phase 3 - Paired Sample T-Tests for ARCS sub-categories.

The results from Table 58, indicate that only Attention vs Relevance results have a statistically significant difference. Meaning overall, the average student response on the ARCS subcategories for the e-learning prototype are broadly balanced and aligned.

6.6.5.2 IMMS Internal Reliability

As discussed in section 6.2.4.1, the internal reliability of the IMMS instrument was originally established by Keller (2006); however, it is good practice to re-establish this reliability in the study itself. Refer to Table 59 for the Cronbach alpha results for Phase 3. Much is written on the threshold values for Cronbach's alpha; Nunnally (2017) advises that the level of reliability depends on how the measure will be used, and recommends .70 and above for basic research. Others, such as Churchill et al. (Churchill & Peter 1984), and Loewenthal and Eysenck (2001), advise that .60 can be acceptable. Based on this, we ascertain that the internal consistency for the Attention and Confidence sub-scales are questionable, but that the remaining sub-scales and the overall IMMS scale reliability have good to excellent internal consistency.

Scale	Reliability Estimate (Cronbach α)	Items in Scale
Attention	.59	12
Relevance	.80	9
Confidence	.50	9
Satisfaction	.90	6
Total Scale	.89	36

Table 59: Phase 3 IMMS Cronbach's alpha results

6.6.6 Learning Styles and Multi-modal Approach (VARK)

6.6.6.1 Participants

From the 66 student participants in Phase 3, 65 participants responded to the VARK instrument. There was negligible non-response to the VARK questions; in any case, even a non-response is acceptable since for each question there can be zero, one, or multiple responses from each participant.

6.6.6.2 Survey Response

The student participants offered 1860 individual responses to the VARK instrument, which were grouped according to Visual, Aural, Read-Write and Kinaesthetic modalities. With reference to Figure 66 the modal preference across all students are comparatively balanced.

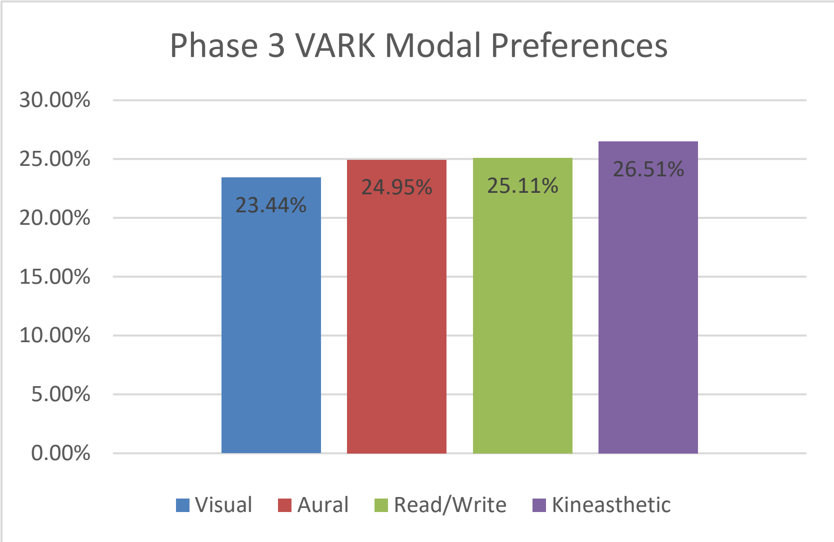


Figure 66: Phase 3 - VARK modal preferences for students

With reference to Table 60, the VARK sub-category response distributions were tested for normality using the Kolmogorov-Smirnov test, with only the Aural sub-category considered as normal. In accordance with section 3.6.5.1, instead of moving to non-parametric tests, the results from both parametric and non-parametric tests are presented.

	Kolmogorov-Smirnov[a]		
	Statistic	df	Sig.
Visual	.13	65	.01
Aural	.11	65	.06
Read/Write	.12	65	.02
Kinaesthetic	.15	65	.00

[a]. Lilliefors Significance Correction

Table 60: Phase 3 - Kolmogorov-Smirnov results for VARC sub-categories

With reference to Table 61 and Table 62, both parametric and non-parametric tests reflect that only Visual and Kinaesthetic sub-categories have a statistically significant difference. The differences between the other VARK subcategories are not statistically significant, which in turn offers support to the multi-modal approach proposed in the e-learning pedagogy.

Paired Samples Test

		Paired Differences					t	df	Sig. (2-tailed)
		Mean	Std. Deviation	Std. Error Mean	95% Confidence Interval of the Difference				
					Lower	Upper			
Pair 1	Visual - Aural	-.43	3.05	.39	-1.19	.33	-1.14	64	.26
Pair 2	Visual – Read/Write	-.48	2.88	.36	-1.19	.24	-1.33	64	.19
Pair 3	Visual - Kinaesthetic	-.88	3.50	.43	-1.75	-.01	-2.02	64	.05
Pair 4	Aural – Read/Write	-.05	3.25	.40	-.85	.76	-.12	64	.91
Pair 5	Aural - Kinaesthetic	-.45	3.03	.38	-1.20	.31	-1.19	64	.24
Pair 6	Read/Write - Kinaesthetic	-.40	3.48	.43	-1.26	.46	-.93	64	.36

Table 61: Phase 3 - Paired Sample T-Test for VARK sub-categories.

		Sig.
Pair 1	Visual - Aural	.22
Pair 2	Visual – Read/Write	.19
Pair 3	Visual - Kinaesthetic	.02
Pair 4	Aural – Read/Write	.80
Pair 5	Aural - Kinaesthetic	.29
Pair 6	Read/Write - Kinaesthetic	.22

Table 62: Phase 3 - Related Samples Wilcoxon Signed Rank test for VARK sub-categories.

A positive result in relation to multi-modal learning is that with N=45, on average (Mdn=4, M=3.60 SD=0.94) the student participants **agreed (4)** with the statement *"The use of different methods to represent the same learning content helped my understanding."* Refer to Figure 67 for the associated frequency distribution, which is not normal, is negatively skewed and kurtosis static. With the removal of two outliers, N=43 and the mean average (Mdn=4, M=3.72 SD=0.77) increased.

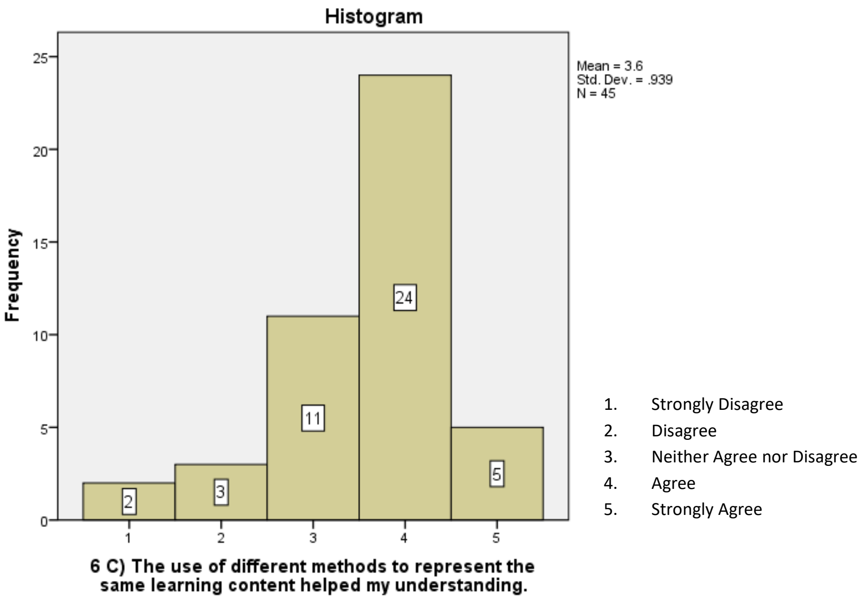


Figure 67: Phase 3- The use of different methods to represent the same learning content helped my understanding.

A further weakly positive result for multi-modal learning is that with N=39, on average (Mdn=3, M=3.00 SD=0.95) the student participants **neither agreed nor disagreed (3)** with the statement "*The use of different methods to represent the same learning content made me feel overloaded.*"

6.6.7 Student Learning Performance

6.6.7.1 Participants

From the 66 student participants in Phase 3, 56 students attempted the pre- and post-tests. After removing all students: who did not get a result for both tests; who acknowledged they had used other learning materials; or who spent zero time on both Level-3 and Level-4 of the e-learning prototype, the number of viable pre- and post-test participants remaining was 48.

6.6.7.2 Student Engagement with the E-learning Prototype

Prior to taking the post-test, the students used the four levels of the e-learning software prototype. With reference to Table 63, the average duration of student engagement with e-learning software is reported with and without outliers. The frequency distributions for the student engagement durations are represented in the histograms in Figure 68 to Figure 71.

	N	Min	Max	Median	Mean	Std. Deviation	Frequency Distribution
Level-1 Duration	48	21	300	99.50	103.81	53.30	Refer to Figure 68
Outliers Removed	45	21	198	96.00	93.89	36.68	
Level-2 Duration	48	0	57	14.50	16.79	13.24	Refer to Figure 69
Outliers Removed	46	0	45	14.00	15.08	10.58	

	N	Min	Max	Median	Mean	Std. Deviation	Frequency Distribution
Level-3 Duration	48	0	167	46.00	49.19	34.04	Refer to Figure 70
Outliers Removed	45	0	79	45.00	41.89	19.05	
Level-4 Duration	48	0	107	23.50	33.65	26.58	Refer to Figure 71

Table 63: Phase 3 - Average duration of engagement with the four levels of e-learning software

As detailed in Table 63, Figure 68 reflects a positively skewed and leptokurtic distribution (N=48) where the average student learning duration for Level-1 was (Mdn =99.50, M=103.81, SD=53.30).

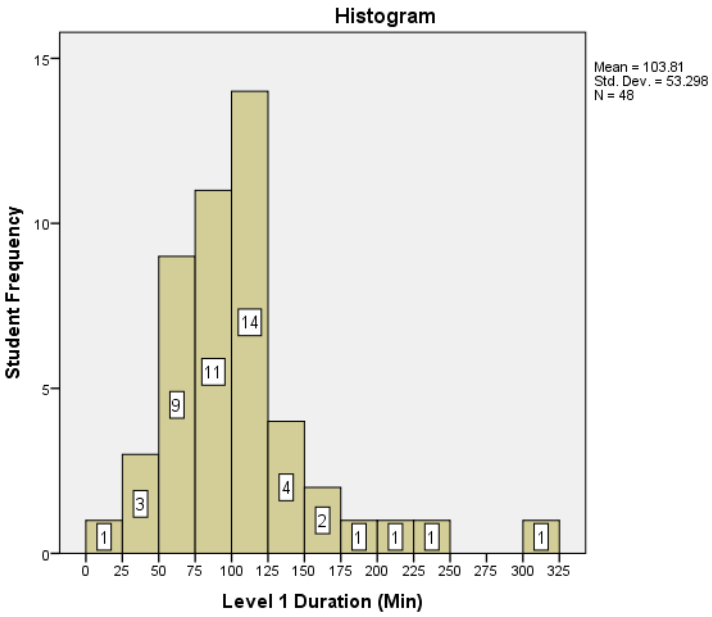


Figure 68: Phase 3 - Duration of student engagement with Level-1

As detailed in Table 63, Figure 69 reflects a positively skewed and leptokurtic distribution (N=48) where the average student learning duration for Level-2 was (Mdn =14.50, M=16.79, SD=13.24).

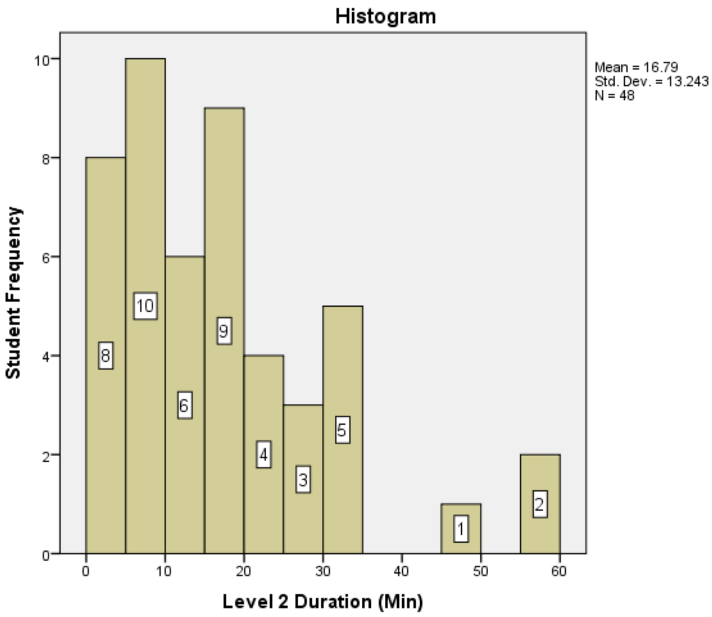


Figure 69: Phase 3 - Duration of student engagement with Level-2

As detailed in Table 63, Figure 70 reflects a positively skewed and leptokurtic distribution (N=48) where the average student learning duration for Level-3 was (Mdn =46.00, M=49.19, SD=34.03).

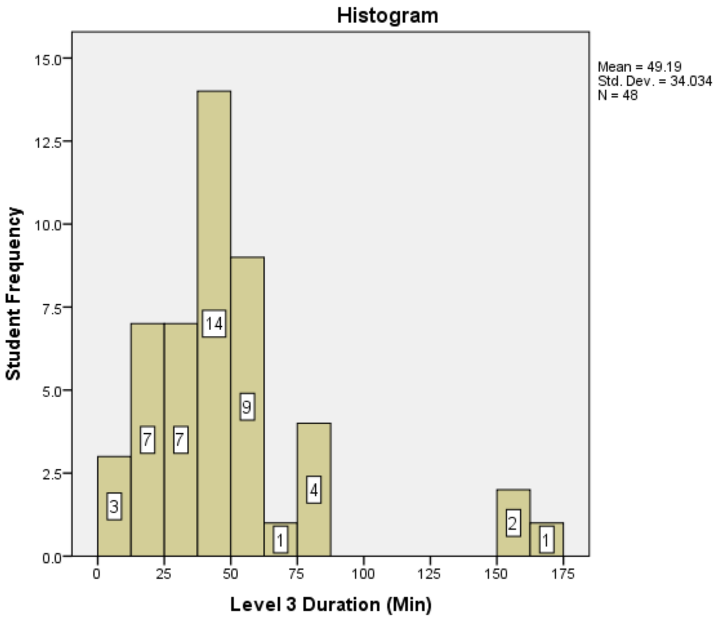


Figure 70: Phase 3 - Duration of student engagement with Level-3

As detailed in Table 63, Figure 71 reflects a positively skewed and kurtosis static distribution (N=48) where the average student learning duration for Level-4 was (Mdn =23.50, M=33.65, SD=26.58).

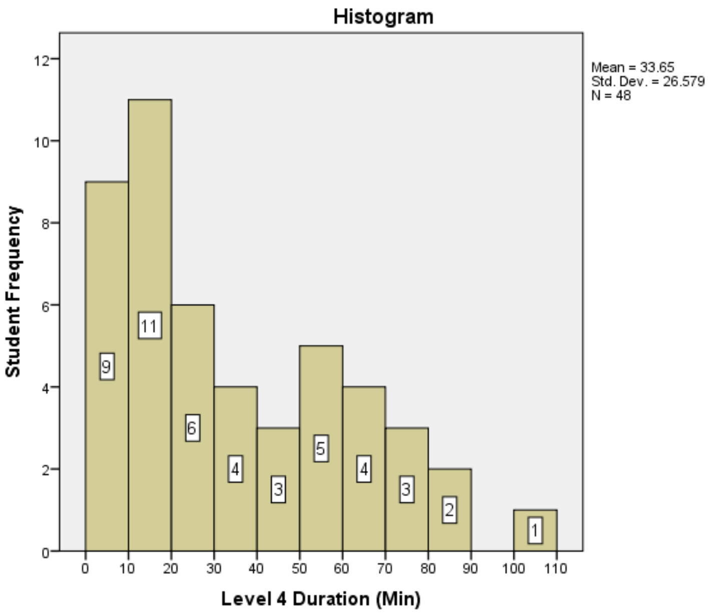


Figure 71: Phase 3 - Duration of student engagement with Level-4

It is important to recall that Level-1 and Level-2 of the e-learning software provide foundational concepts on algorithms and computational thinking, whereas Level-3 and Level-4 provide learning material on flowcharts and pseudocode, which are of direct relevance to the pre- post-test exam. These durations have therefore been analysed in relation to all four levels (L1L2L3L4) of the e-learning software, and separately for Level-3 and -4 (L3L4) of the e-learning software. Using the Kolmogorov-Smirnov test, the distributions for L1L2L3L4 and L3L4 durations, with and without outliers, are **not** all normal. Therefore, Table 64 reflects the 95% Confidence Interval with and without outliers, based on median learning duration; these are constructed without any distribution assumption.

			95% Confidence Interval for Median					Coefficient of Variation
Variable	N	Mdn	Lower Bound	Upper Bound	Actual Coverage	Price- Related Differential	Coefficient of Dispersion	Median Centred
L1L2L3L4	48	196.50	172.00	219.00	97.1%	1.00	.28	44.0%
No Outliers	44	188.00	167.10	205.00	95.1%	1.00	.21	27.2%
L3L4	48	64.50	56.00	100.00	97.1%	1.00	.55	80.0%
No Outliers	46	63.00	52.00	99.00	97.4%	1.00	.47	63.3%

Table 64: Phase 3 - Confidence Intervals for the median learning duration for the e-learning software

6.6.7.3 Collaborative Learning Activities and Individual Assignments

The student participants showed a high level of engagement with the practice and quiz activities in the e-learning software; however, for the most part, this did not extend to collaborative learning and assignment activities hosted on the collaborative learning environment. Refer to Table 65 for a summary of student responses to collaborative learning and assignment activities.

Software	Title and Description	Response Count	Comment
Level-1 White	**Decomposition Activity** Adapted from a GCSE Non-Examinable Assessment (NEA). The students are asked to consider two problem areas and decompose them into smaller sub-problems	0 responses	A moderately challenging activity to analyse a problem and break it down into smaller more manageable sub-problems.
Level-1 White	**The Characteristics of Algorithms** Forum question for students to discuss the characteristics of algorithms, whether they are important and why, and if algorithms are only used in computers?	13 posts by 12 authors. 31 Views	Most of the responses incorrectly define the characteristics of computational thinking instead of algorithms. All students identify the importance of Algorithms. Except for one student, all students identify that Algorithms are not only used with computers.

Software	Title and Description	Response Count	Comment
Level-1 White	**Think about the various criteria that can be used to evaluate the going to school algorithms.** Individual Assignment to outline different evaluation criteria and then evaluate the four algorithms to go to school.	31 responses from 25 participants. Students did not use the assignment mechanism, instead of answering with comments, similar to a forum question.	10 responses are incorrect, three of which have misunderstood the question. Most of the remaining responses were copy / paste from the hint dialogue in the e-learning software. Three responses show a level of critical thinking in evaluating the algorithms and offering a recommendation.
Level-2 Yellow	**Understanding the example Algorithm** Forum questions to discuss what a simple algorithm does and to discuss whether the students' found the pseudocode or flowchart version easier to understand.	15 posts by 14 authors. 47 Views	Most of the responses are underdeveloped and four responses were copy / paste from the hint dialogue in the e-learning software.
Level-3 Orange	**Direction Indicators Algorithm** An individual assignment to create a flowchart algorithm for the direction indicator in a car.	0 responses	A moderately challenging assignment which is scaffolded by multiple hint files that progressively complete the algorithm.
Level-3 Orange	**Trainers Algorithm Flowchart** An individual assignment to create a flowchart to convert US trainer sizes to the equivalent EU size.	0 responses	A moderately challenging assignment which is scaffolded by multiple hint files that progressively complete the algorithm.
Level-4 Blue	**Practice in writing Pseudocode – Dice Game** An individual assignment to create a pseudocode algorithm of a given flowchart representing a dice game.	0 responses	A moderately challenging assignment which is scaffolded by multiple hint dialogues that progressively complete the pseudocode.
Level-4 Blue	**Partner Work to Create a Dog Age Algorithm**	5 responses uploaded, but	A moderately challenging assignment which is scaffolded by multiple hint dialogues that

Software	Title and Description	Response Count	Comment
	Pair work to create a pseudocode algorithm converts a dog's age to the human equivalent.	all were blank documents.	progressively complete the pseudocode.

Table 65: Phase 3 - Summary of student responses to collaborative learning and assignment activities

An important result in relation to learning performance is that none of the students attempted the four assignment activities in Level-3 and -4, which would have given them an opportunity to practice skills transferable to the pre-, post-test.

6.6.7.4 *Learning Performance*

6.6.7.4.1 Descriptive Statistics

For reporting purposes, the pre-, post-test and change variables have been transformed to percentage values. Table 66, reflects descriptive statistics for %Pre-Test, %Post-Test and %Change, and the associated frequency distributions are reflected in Figure 72 to Figure 74. In summary, with N=48, an improvement in learning performance between pre-test and post-test is indicated (subject to further statistical analysis):

- %Pre-Test had a mean average of 15.93% (SD=11.38), 95% CI [12.62%, 19.23%].
- %Post-Test had a mean average of 35.15% (SD=13.80), 95% CI [31.14%, 39.16%].
- %Change had a mean average of 19.22% points increase (SD=12.20), 95% CI [15.68%, 22.76%].

N=48			Statistic	Std. Error
%Pre-Test	Mean		15.93	1.64
	95% Confidence Interval for Mean	Lower Bound	12.62	
		Upper Bound	19.23	
	5% Trimmed Mean		14.98	
	Median		12.90	
	Variance		129.48	
	Std. Deviation		11.38	
	Minimum		.00	
	Maximum		54.84	
	Range		54.84	
	Interquartile Range		12.90	
	Skewness		1.21	.34
	Kurtosis		2.67	.67

N=48			Statistic	Std. Error
%Post-Test	Mean		35.15	1.99
	95% Confidence Interval for Mean	Lower Bound	31.14	
		Upper Bound	39.16	
	5% Trimmed Mean		34.38	
	Median		32.26	
	Variance		190.52	
	Std. Deviation		13.80	
	Minimum		12.90	
	Maximum		83.87	
	Range		70.97	
	Interquartile Range		19.35	
	Skewness		1.08	.34
	Kurtosis		2.02	.67
%Change	Mean		19.22	1.76
	95% Confidence Interval for Mean	Lower Bound	15.68	
		Upper Bound	22.76	
	5% Trimmed Mean		19.06	
	Median		19.35	
	Variance		148.75	
	Std. Deviation		12.20	
	Minimum		-6.45	
	Maximum		51.61	
	Range		58.06	
	Interquartile Range		16.13	
	Skewness		.20	.34
	Kurtosis		.10	.67

Table 66: Phase 3 - Descriptive statistics for %Pre-Test, %Post-Test and %Change.

As detailed in Table 66, Figure 72 shows (N=48) a positively skewed and leptokurtic frequency distribution for %Pre-Test with average (Mdn=12.90%, M=15.93%, SD=11.38). It should be noted that removal of outliers removes the positive skew and leptokurtic kurtosis.

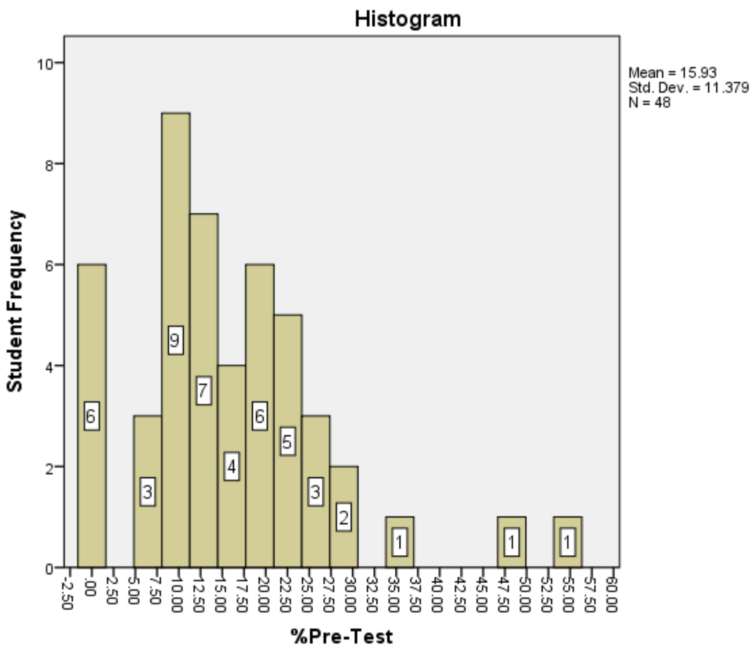


Figure 72: Phase 3 - Frequency Distribution for %Pre-Test.

As detailed in Table 66, Figure 73 shows (N=48) a positively skewed and leptokurtic frequency distribution for %Post-Test with average (Mdn=32.26%, M=35.15%, SD=13.80). It should be noted that removal of outliers removes the positive skew and leptokurtic kurtosis.

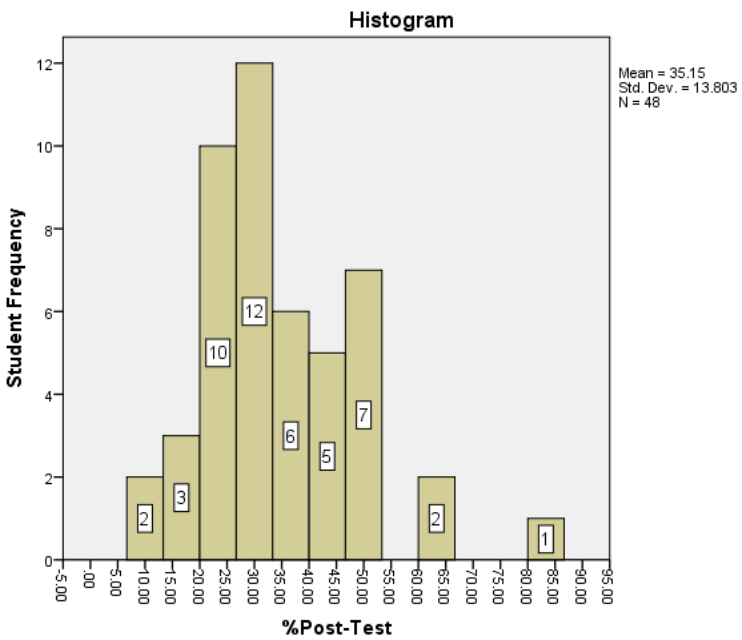


Figure 73: Phase 3 - Frequency Distribution for %Post-Test

As detailed in Table 66, Figure 74 shows (N=48) a normal frequency distribution for %Change with average (Mdn=19.35%, M=19.22%, SD=12.20).

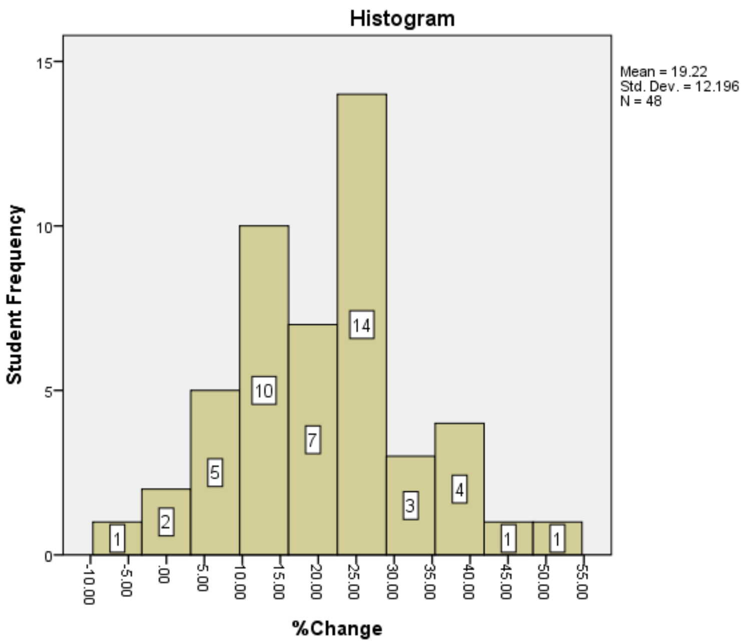


Figure 74: Phase 3 - Frequency Distribution for %Change.

Outliers are identified for %Pre-Test, %Post-Test and %Change; hence, the associated descriptive statistics without outliers are reflected in Table 67. In summary, with outliers removed, an improvement in learning performance between pre-test and post-test remains evident (subject to further statistical analysis):

- N= 46, %Pre-Test had a mean average of 14.38% (SD=8.70), 95% CI [11.79%, 16.96%].
- N=47, %Post-Test had a mean average of 34.11% (SD=11.91), 95% CI [30.61%, 37.61%].
- N=47, %Change had a mean average of 18.53% points increase (SD=11.34), 95% CI [15.20%, 21.86%].

Outliers Removed			Statistic	Std. Error
%Pre-Test	Mean		14.38	1.28
N=46	95% Confidence Interval for Mean	Lower Bound	11.79	
		Upper Bound	16.96	
	5% Trimmed Mean		14.20	
	Median		12.90	
	Variance		75.70	
	Std. Deviation		8.70	
	Minimum		.00	
	Maximum		35.48	
	Range		35.48	
	Interquartile Range		10.48	
	Skewness		.12	.35

Outliers Removed			Statistic	Std. Error
	Kurtosis		-.37	.69
%Post-Test	Mean		34.11	1.74
N=47	95% Confidence Interval for Mean	Lower Bound	30.61	
		Upper Bound	37.61	
	5% Trimmed Mean		33.83	
	Median		32.26	
	Variance		141.95	
	Std. Deviation		11.91	
	Minimum		12.90	
	Maximum		61.29	
	Range		48.39	
	Interquartile Range		19.35	
	Skewness		.43	.35
	Kurtosis		-.39	.68
%Change	Mean		18.53	1.65
N=47	95% Confidence Interval for Mean	Lower Bound	15.20	
		Upper Bound	21.86	
	5% Trimmed Mean		18.59	
	Median		19.35	
	Variance		128.70	
	Std. Deviation		11.34	
	Minimum		-6.45	
	Maximum		41.94	
	Range		48.39	
	Interquartile Range		16.13	
	Skewness		-.09	.35
	Kurtosis		-.39	.68

Table 67: Phase 3 - Descriptive statistics for %Pre-Test, %Post-Test and %Change (outliers removed)

6.6.7.4.2 Paired Sample T-Test

To test whether there is a change in learning performance between %Pre-Test and %Post-Test, a Paired Sample T-Test was carried out. With reference to Table 68, the Paired Sample T-Test was carried out, with and without outliers. Both showed a statistically significant learning performance improvement of approximately 19% points.

	Paired Differences					t	df	Sig. (2-tailed)
	Mean	Std. Deviation	Std. Error Mean	95% Confidence Interval of the Difference				
				Lower	Upper			
%Post-Test - %Pre-Test (N=48)	19.22	12.12	1.76	15.68	22.76	10.92	47	.00
%Post-Test - %Pre-Test (No Outlier, N=46)	19.36	12.15	1.79	15.75	22.96	10.81	45	.00

Table 68: Phase 3 - Paired Sample T-Test for %Post-Test and %Pre-Test

Using the Kolmogorov-Smirnov test, the distribution for %Post-Test is assessed as not normal, hence failing one of the assumptions for the use of a T-Test. To compensate for this and validate the above results, the T-Test was re-run using the bootstrapping option, and additionally further validated using non-parametric testing (Wilcoxon Signed-Ranks Test).

6.6.7.4.3 Paired Sample T-Test using Bootstrapping

With reference to Table 69, the Paired Sample T-Test was carried out using the Bootstrap option for 1000 samples, with and without outliers. Both showed a statistically significant learning performance improvement of approximately 19% points.

Bootstrap for Paired Samples Test (1000 samples)

	Mean	Bootstrap[a]				
		Bias	Std. Error	Sig. (2-tailed)	95% Confidence Interval	
					Lower	Upper
%Post-Test - %Pre-Test (N=48)	19.22	.06	1.75	.00	16.06	22.85
%Post-Test - %Pre-Test No Outlier (N=46)	19.36	.02	1.79	.00	15.64	22.72

Table 69: Phase 3 - Paired Sample T-Test for %Post-Test and %Pre-Test using Bootstrap

6.6.7.4.4 Wilcoxon Signed-Ranks Test

A Wilcoxon Signed-Ranks Test (with outliers N=48) indicated that the median %Post-Test scores were statistically significantly higher than the median %Pre-Test Scores Z= -5.86, p < .00.

A Wilcoxon Signed-Ranks Test (without outliers N=46) indicated that the median %Post-Test scores were statistically significantly higher than the median %Pre-Test Scores Z=-5.74, p < .00.

Following on from the above results, Table 70 outlines the 95% Median Confidence Interval for %Change, with and without outliers. In summary:

- N=46, %Change had a median average of 20.97% points increase, 95% CI [12.90%, 25.81%].
- N=45, %Change had a median average of 19.35% points increase, 95% CI [12.90%, 22.58%].

Variable	N	Mdn	95% Confidence Interval for Median Lower Bound	Upper Bound	Actual Coverage	Price Related Differential	Coefficient of Dispersion	Coefficient of Variation Median Centred
%Change	46	20.97	12.90	25.81	97.4%	1.00	.43	54.2%
%Change No Outliers	45	19.35	12.90	22.58	96.4%	1.00	.43	53.8%

Table 70: Phase 3 - Confidence Interval for Median %Change between %Post-Test - %Pre-Test

6.6.7.5 Learning Performance vs GCSE Grade Boundaries

The pre-, post-test is based on sample exam questions from paper 1 of the new Computer Science GCSEs from the following examination boards: EDEXCEL, OCR and AQA. The new computer science specification started in 2016 and will be first examined in 2018, hence the grade boundaries have not been released. Regarding the new GCSE grading scale, factsheets from the Department for Education (2017) advise that the old letter and new numeric grading are not directly comparable, but offer three points of alignment:

1. The bottom of new grade 7 is aligned with the bottom of current grade A;
2. The bottom of new grade 4 is aligned with the bottom of current grade C; and
3. The bottom of new grade 1 is aligned with the bottom of current grade G.

With reference to recent GCSE Computer Science grade boundaries from EDEXCEL (Pearson 2016), OCR (2017) and AQA (2016), Table 71 provides a realistic theoretical model of the grade boundaries for the new GCSE specification.

Numeric Grade Equivalent	Letter Grade	AQA		Edexcel		OCR		Mean
Total		84	100.00%	200	100.00%	80	100.00%	100.00%
9 8	A*	73	86.90%	157	78.50%	56	70.00%	78.47%
7	A	62	73.81%	129	64.50%	47	58.75%	65.69%
6 5	B	47	55.95%	101	50.50%	38	47.50%	51.32%
4	C	33	39.29%	73	36.50%	29	36.25%	37.35%
3 2	D	26	30.95%	61	30.50%	23	28.75%	30.07%
	E	19	22.62%	49	24.50%	17	21.25%	22.79%
	F	13	15.48%	37	18.50%	12	15.00%	16.33%
1	G	7	8.33%	25	12.50%	7	8.75%	9.86%
U	U	0	0.00%	0	0.00%	0	0.00%	0.00%

Table 71: Phase 3 - Model for GCSE Computer Science (2016 specification) grade boundaries

The aforementioned model theorises that in the GCSE Computer Science population, a Grade F (Low Grade 2), is approximately 16.33%.

To test whether the average %Pre-Test result would attain Grade F, a one sample T-Test was carried out. With Reference to Table 72, the one sample T-Test was carried out with and without outliers.

One-Sample Test (%Pre-Test)

	Test Value = 16.33					
	t	df	Sig. (2-tailed)	Mean Difference	95% Confidence Interval of the Difference: Lower	95% Confidence Interval of the Difference: Upper
%Pre-Test N=48	-0.25	47	.81	-0.40	-3.71	2.90
%Pre-Test (No Outlier, N=46)	-1.52	45	.14	-1.95	-4.54	0.63

Table 72: Phase 3 - One sample T-Test of %Pre-Test towards Grade F threshold

Furthermore, with Reference to Table 73, the one sample T-Test was also carried out using the Bootstrap option for 1000 samples, with and without outliers.

Bootstrap for One-Sample Test (%Pre-Test)

		Bootstrap[a]				
	Mean Difference	Bias	Std. Error	Sig. (2-tailed)	95% Confidence Interval: Lower	95% Confidence Interval: Upper
%Pre-Test N=48	-0.40	0.12	1.65	.81	-3.36	3.16
%Pre-Test (No Outlier, N=46)	-1.95	0.01	1.28	.15	-4.46	0.52

a. Bootstrap results are based on 1000 bootstrap samples

Table 73: Phase 3 - One sample T-Test of %Pre-Test towards Grade F threshold using Bootstrap

Since all $p > .05$, we cannot reject the null hypothesis that the %Pre-Test mean is equal to the hypothesised Grade F target value.

The aforementioned Grade Boundary model also theorises that in the GCSE Computer Science population a Grade C (Grade 4 – Standard Pass) is approximately 37.35%.

To test whether the average %Post-Test result would attain Grade C, a one sample T-Test was carried out. With reference to Table 74, the one sample T-Test was carried out with and without outliers.

One-Sample Test (%Post-Test)

	Test Value = 37.35					
	t	df	Sig. (2-tailed)	Mean Difference	95% Confidence Interval of the Difference	
					Lower	Upper
%Post-Test N=48	-1.11	47	.28	-2.20	-6.21	1.81
%Post-Test (No Outlier, N=47)	-1.86	46	.07	-3.24	-6.74	0.26

Table 74: Phase 3 - One sample T-Test of %Post-Test towards Grade C threshold

Furthermore, with Reference to Table 75, the one sample T-Test was also carried out using the Bootstrap option for 1000 samples, with and without outliers.

Bootstrap for One-Sample Test (%Post-Test)

	Mean Difference	Bootstrap[a]				
		Bias	Std. Error	Sig. (2-tailed)	95% Confidence Interval	
					Lower	Upper
%Post-Test	-2.20	0.05	2.01	.28	-5.83	1.96
%Post-Test (No Outlier, N=47)	-3.24	0.06	1.77	.08	-6.70	0.42

[a] Bootstrap results are based on 1000 bootstrap samples

Table 75: Phase 3 - One sample T-Test of %Post-Test towards Grade C threshold using Bootstrap

Since all $p > .05$, we cannot reject the null hypothesis that the %Post-Test mean is equal to the hypothesised Grade C target value.

6.6.7.6 Correlation Analysis

In accordance with the correlation analysis approach outlined in section 3.6.5.2, correlation results are reported in two tiers that reflect the strength of the result:

1. Tier 1: A positive or negative correlation effect of .1 or more, and p < .05.
2. Tier 2: A positive or negative correlation effect of .1 or more, and Bootstrapping Confidence Interval (CI) does not cross over the 0 threshold. (i.e. CI is between -.09 and 1 or .09 and -1)

6.6.7.6.1 Time Engaged with E-learning Software vs. %Post-Test, %Change and KS4 Predictions

Table 76, reflects the tiered correlation results for %Post-Test vs. Level-2 Time and All Levels combined.

Spearman's rho				Tier 1 Level2 Time	Tier 2 All Levels Time
%Post-Test	Correlation Coefficient			.32	.21
	Sig. (2-tailed)			.03	.14
	N			48	48
	Bootstrap[c]	Bias		-.00	-.00
		Std. Error		.13	.14
		95% Confidence Interval	Lower	.07	-.05
			Upper	.55	.49

Table 76: Phase 3 - Tiered correlation results for %Post-Test vs. learning times

Table 77, reflects the correlation result for %Change vs. Level-3 Time.

Spearman's rho				Tier 2 Level3 Time
%Change	Correlation Coefficient			-.23
	Sig. (2-tailed)			.12
	N			48
	Bootstrap[c]	Bias		.01
		Std. Error		.15
		95% Confidence Interval	Lower	-.49
			Upper	.09

Table 77: Phase 3 - Tiered correlation results for %Change vs. learning times

Table 78, reflects the tiered correlation results for Key Stage 4 Prediction (KS4Prediction) vs. Level-1 Time, Level-4 Time, and Level-3 and -4 combined time.

Spearman's rho			Tier 1 Level1 Time	 Level4 Time	 Level 3 and 4 Time
KS4Prediction	Correlation Coefficient		-.32	.47	.38
	Sig. (2-tailed)		.03	.00	.01
	N		48	48	48
	Bootstrap[c]	Bias	.00	-.01	-.01
		Std. Error	.15	.13	.13

Spearman's rho				Tier 1 Level1 Time	Tier 1 Level4 Time	Tier 1 Level 3 and 4 Time
		95% Confidence Interval	Lower	-.59	.19	.10
			Upper	.00	.70	.61

Table 78: Phase 3 - Tiered correlation results for KS4Prediction vs. learning times

6.6.7.6.2 VARK Modalities vs. Time Engaged with e-learning software, %Post-Test and %Change

Table 79, reflects the correlation result for Aural modality vs. %Post-Test.

Spearman's rho				Tier 2 %Post-Test
Aural	Correlation Coefficient			-.25
	Sig. (2-tailed)			.09
	N			47
	Bootstrap	Bias		.01
		Std. Error		.14
		95% Confidence Interval	Lower	-.51
			Upper	.05

Table 79: Phase 3 - Tiered correlation results for aural modality vs. %Post-Test, Level-3 Time, and Level-4 Time

Table 80 reflects the correlation result for Kinaesthetic modality vs. Level-4 time.

Spearman's rho				Tier 2 Level4 Time
Kinaesthetic	Correlation Coefficient			.22
	Sig. (2-tailed)			.14
	N			47
	Bootstrap[c]	Bias		-.00
		Std. Error		.15
		95% Confidence Interval	Lower	-.07
			Upper	.50

Table 80: Phase 3 - Tiered correlation results for kinaesthetic modality vs. Learning Times

6.6.7.6.3 IMMS Results vs. Time engaged with E-learning software, %Post-Test and %Change

Table 81 reflects the tiered correlation results for IMMS Relevance vs. Learning Times.

Spearman's rho				Tier 2 Level2 Time	Tier 2 Level 3 and 4 Combined Time
Student Relevance	Correlation Coefficient			.32	.32
	Sig. (2-tailed)			.08	.09
	N			30	30
	Bootstrap[c]	Bias		-.01	-.01
		Std. Error		.17	.19
		95% Confidence Interval	Lower	-.04	-.09
			Upper	.61	.67

Table 81: Phase 3 - Tiered correlation results for IMMS Relevance vs. Learning Times

Table 82 reflects the tiered correlation results for IMMS Satisfaction vs. Learning Times.

Spearman's rho				Tier 2 Level3 Time	Tier 2 Level 3 and 4 Combined Time
Student Satisfaction	Correlation Coefficient			.32	.32
	Sig. (2-tailed)			.08	.08
	N			30	30
	Bootstrap[c]	Bias		-.01	-.01
		Std. Error		.20	.20
		95% Confidence Interval	Lower	-.07	-.08
			Upper	.68	.69

Table 82: Phase 3 - Tiered correlation results for IMMS Satisfaction vs. Learning Times

Table 83 reflects the tiered correlation results for IMMS Overall vs. Learning Times.

Spearman's rho				Tier 1 Level2 Time	Tier 2 Level 3 and 4 Combined Time
Student IMMS Overall	Correlation Coefficient			.37	.33
	Sig. (2-tailed)			.04	.08
	N			30	30
	Bootstrap[c]	Bias		-.01	-.01
		Std. Error		.17	.19
		95% Confidence Interval	Lower	-.01	-.07
			Upper	.67	.66

Table 83: Phase 3 - Tiered correlation results for IMMS Overall vs. Learning Times

6.6.7.6.4 Survey Instrument Questions vs. %Post-Test and %Change

Table 84 reflects the correlation results for %Post-Test vs. the following survey instrument questions.

1. 4 A) All things considered, the e-learning software is easy to use.
2. 4 J) The e-learning software is reliable (i.e. does not contain bugs or errors).
3. 12 B) The use of different methods to represent the same learning content made me feel overloaded.

Spearman's rho				Tier 2 4 A)	 4 J)	 12 B)
%Post-Test	Correlation Coefficient			.32	.32	-.33
	Sig. (2-tailed)			.08	.08	.11
	N			30	30	25
	Bootstrapc	Bias		-.01	-.01	.01
		Std. Error		.17	.19	.16
		95% Confidence Interval	Lower	-.04	-.09	-.60
			Upper	.61	.62	.05

Table 84: Phase 3 - Tier 2 correlation results for %Post-Test and the survey instrument

Table 85 reflects the correlation result for %Change vs. the following survey instrument questions.

- 12 B) The use of different methods to represent the same learning content made me feel overloaded.

<table>
<tr><th colspan="4"></th><th>Tier 1</th></tr>
<tr><th colspan="4">Spearman's rho</th><th>12 B)</th></tr>
<tr><td rowspan="7">%Change</td><td colspan="3">Correlation Coefficient</td><td>-.41</td></tr>
<tr><td colspan="3">Sig. (2-tailed)</td><td>.04</td></tr>
<tr><td colspan="3">N</td><td>25</td></tr>
<tr><td rowspan="4">Bootstrap[c]</td><td colspan="2">Bias</td><td>.01</td></tr>
<tr><td colspan="2">Std. Error</td><td>.18</td></tr>
<tr><td rowspan="2">95% Confidence Interval</td><td>Lower</td><td>-.69</td></tr>
<tr><td>Upper</td><td>-.01</td></tr>
</table>

Table 85: Phase 3- Tier 1 correlation results for %Change and the survey instrument

As previously noted, the research findings from Phase 1 and Phase2-Cycle1 have already been published; additionally, it is planned that by the middle of 2019, the full set of research findings will be published to a wider academic audience.

6.7 E-learning Evaluation Protocol Results

This section reports how Phase 1 identified the need for an e-learning evaluation protocol, the feedback in Phase 2 from education experts and pilot usage, and a summary of the Phase 3 findings from the e-learning evaluation workshop. The Phase 3 findings focus on:

1. School characteristics in relation to e-learning,
2. Teacher characteristics in relation to e-learning,
3. Teacher feedback on the e-learning evaluation protocol,
4. Guidelines on the typical duration for evaluation activities,
5. The reliability and validity of evaluation results, and
6. Suggested refinements to the detailed evaluation procedures.

6.7.1 Phase 1: Identifying the Need for an E-learning Evaluation Protocol

As discussed in section 5.3, in Phase 1 an initial E-Learning Evaluation rubric was constructed; this initial rubric acted as a strawman to be deconstructed, leading to some important areas of consideration:

1. The evaluation of Learning Objective Coverage is open to subjective interpretation and needs to be more rigorously defined.
2. This rubric considers that all learning objectives are equal, whereas in a particular educational setting, different learning objectives may have varying levels of importance.
3. This rubric counts the application of each heuristic, but does not measure the quality of implementation.
4. This approach implies greater heuristic coverage is better, but this may not be the case for all heuristics. For example, should we expect to *"Use Social Interaction as a basis for learning"* in all screens. Logically, it is more realistic that each heuristic must be evaluated within the context of the specific educational setting.
5. The process of analysing each screens for heuristic coverage is a very valuable tool during e-learning software design or evaluation in identifying weak areas and ways to improve the e-learning software.

Despite these areas of consideration, the Phase 1 e-learning prototype was evaluated as follows[33]:

- Based on the seven learning objectives defined, the Learning Objective Coverage is 75.71%.
- Pedagogical Heuristics Coverage is 35.60%
- The weighted pedagogical coverage (75.71% * 35.60%) is 26.96%.

A weighted pedagogical coverage of 27% (rounded) can potentially be perceived as low; however, this relates to two points:

[33] For further details, please refer to Vol 3 Appendix Q for the calculation breakdown

1. Some heuristics were genuinely underutilised in the Phase 1 e-learning software prototype; this was remedied in Phase 2.
2. Consideration of point 4 above has a significant impact on the pedagogical coverage; when the educational setting is considered in an evaluation it has a significant impact on whether a learning objective or heuristic is relevant within the setting, and if relevant, what its relative importance is.

6.7.2 Phase2-Cycle2: Piloting the E-learning Evaluation Protocol

Feedback on the Phase2-Cycle2 e-learning evaluation protocol was provided by education experts, and by the researcher piloting the protocol for the evaluation of Level-1 and -2 of the prototype software.

6.7.2.1 Education Experts

The review of the Phase2-Cycle2 e-learning software evaluation protocol was given by three education experts; this feedback was based on the document: E-Learning Software Evaluation Protocol v0.1b. In Phase2-Cycle2, the feedback did not structurally affect the evaluation procedure, but was significant in defending decisions and approaches used in the protocol, and in documenting the protocol with enough detail and clarity for effective usage. The main findings from the education expert review were:

1. Greater clarity and detail need to be given on how the e-learning evaluation protocol works in practice.
    - Use diagrams to support the discussion and help the audience to visualise the evaluation steps, and assess the composition of educational value in terms of content quality and pedagogical quality.
2. The evaluation protocol seems to document an "*onerous activity*". Is there a way to make this more efficient and feasible for the busy teacher audience?
3. Greater emphasis needs to be placed on whether all heuristics are equal; specifically, how evaluators judge whether a heuristic is applicable to an educational setting and its level of importance within that setting.
4. Greater clarity and detail need to be given on what the quantitative results really represent.
5. Review and document in more detail the process of how the evaluators might secure knowledge of the heuristics, and the evaluation protocol, before the evaluation activity is undertaken.
6. Discuss in more detail the roles and responsibilities of evaluations, and the experience required of teachers or instructional designers to qualify as expert evaluators.
7. Explain and defend the use of such a wide scale for the level of the support metric.
8. The explanatory text and title need to give greater clarity on what Section 4 is discussing.
9. Technical terms are used within the evaluation protocol; these should be defined.
10. Various grammar and phrasing changes are suggested within the evaluation protocol document.

6.7.2.2 Pilot feedback

Piloting of the e-learning evaluation process confirmed that the overall structure of the protocol steps is functional; additionally, it helped to explain and support the feedback from the education experts by placing it in a more practical context. The main findings from the Phase2-Cycle2 evaluation pilot were:

1. Level-1 and -2 of the prototype software (total learning time of approximately 2.5 hours) were evaluated and individual results recorded in 3 hours and 15 minutes. This is presumed to be an underestimate for a typical evaluator since the researcher has an in-depth knowledge of the software.
2. Sections 3.1, 3.2 and 3.3 of the evaluation protocol are unfocused; they need to be reviewed and rewritten with more detail, clarity, and focus on the teacher audience. Recommendations from education experts give some areas to address.
3. The composition of educational value in terms of content quality and pedagogical quality is not discussed; what each measure, and how they interact, needs to be detailed in the evaluation protocol.
4. On a theoretical level, Section 4 – Step 4 (to remove from consideration learning objectives and heuristics that are not applicable to the particular learning context) is feasible before Step 5 (to spend time to explore the e-learning software). However, in practical terms, it does not work well and remains a speculative exercise. It is more effective to switch the order of these steps.
5. Section 4 – Point 3 does not currently discuss in what scenario the Educational Setting (Learning Context) is given to the evaluators, and in what scenario they define and document it themselves.
6. A glossary is important to explain key terms to the teacher audience.
7. The importance scale is incorrectly reflected as ordinal; it does not reflect the interval number scheme in parallel to scale titles.
8. The scale labels for the bi-directional level of support scale are inconsistent between ‘counteracts’ and ‘supports’ portions of the scale.
9. The excel object embedded in section 6 had an incorrect sequence of menu items for the bi-directional level of support scale. This was causing incorrect calculations for the level of support.
10. The process of transferring quantitative results into the section 6 excel object is cumbersome, requiring multiple iterations of scrolling backwards and forwards within the document; as a workaround, the researcher transferred results into an intermediate text file to consolidate, then used a dual screen setup to transfer the results into the excel object.
11. Reference to a doctorate degree on the title page is not relevant to the teacher audience and can be removed.

6.7.3 Phase 3: Usage of the E-learning Evaluation Protocol

Feedback on the Phase 3 e-learning evaluation protocol was provided by education experts and a workshop used as a vehicle to study the usage of the evaluation protocol. The findings from the workshop are quite lengthy and hence are summarised in this section.

6.7.3.1 Education Expert Feedback

The review of the Phase 3 E-Learning Software Evaluation Protocol was given by two education experts; this feedback was based on the document: E-Learning Software Evaluation Protocol (P3_Group1) v0.3. In Phase 3, the feedback on the e-learning evaluation protocol plateaued and was nominal; it is outlined below:

1. Elaborate in more detail the description of novice, single expert and double expert classification.
2. Elaborate in more detail what pre-training would be given before an e-learning evaluation.
3. Briefly describe what actions should be taken in case the evaluation group cannot reach consensus.
4. Describe the role of facilitator in terms of what is expected from him/her, their knowledge, and who can act as a facilitator.
5. Make minor phrasing and grammar changes.
6. Add figure titles under four inline diagrams.

6.7.3.2 Phase 3: Workshop Findings on the E-learning Evaluation Protocol

The workshop research findings are based on nine computer science / ICT teachers from five private schools and educational institutions. The findings are summarised in Table 86, but are then elaborated with richer qualitative description and quantitative results in Vol 2 Appendix C.

Phase 3 – Workshop Findings on E-learning Evaluation Protocol
Usage of the E-learning Evaluation Protocol **9 teachers in 2 groups**
[±] Both focus groups indicate their schools' limited experience, limited use of e-learning software, and lack of school-wide policy. **[±]** Majority of teachers in both focus groups have limited or no personal experience of integrating e-learning software into their teaching. **[±]** Majority of teachers expressed that they 'always' or 'very often' use the internet and the web to support their teaching. **[+]** Both focus groups recognise the benefits of integrating e-learning software into their teaching. **[+]** Both focus groups expressed that e-learning software can have positive educational and motivational impact. **[-]** Participating teachers acknowledged that there are barriers that discourage them from using e-learning software in their teaching, such as: **[-]** Perceived quality, usability, and syllabus coverage of the software.

[+] It is these perceived issues that the proposed evaluation protocol addresses.

[-] Socio-political and technology barriers to e-learning adoption.

[±] Participating teachers have limited or no experience in selecting or evaluating e-learning software.

[+] If called upon by their schools, teachers would get involved in an e-learning evaluation.

[+] Both focus groups expressed that they could use the heuristics and the evaluation protocol to evaluate e-learning software.

[+] Minimal teacher feedback on how evaluation protocol could be improved.

[-] More time allocated to the hands-on evaluation activity.

[±] The heuristic evaluation criteria must be available throughout the evaluation process.

[±] Timeline analysis of the evaluation activities for a 1-hour e-learning software with six learning objectives estimates that an end-to-end evaluation would take between 5 hr 45 min and 9 hr 30 min.

[+] Validity of the heuristic evaluation results was demonstrated.

[+] Accuracy of the feedback from both groups relating to the known characteristics of the Level-3 prototype software.

[+] Validity and reliability further supported by the comparison of Group-1 and Group-2 heuristic evaluation results.

[-] Validity and reliability of the learning objective evaluation results is open to doubt.

[-] The response by Group-2 on three of the six learning objectives was significantly different to Group-1. These responses from Group-2 show indicators of being atypical or outlier responses.

[±] Postulated that atypical responses were brought about by:

a. Group-2 having an incorrect understanding of the educational setting for the evaluation.
b. Dominant members of Group-2 biasing overall team response.
c. Lack of facilitator mediation to correct the above points.

[±] Evaluation protocol judged to be broadly effective, with some refinements:

[+] Shorter group evaluation report.

[+] Improved facilitator guidelines.

[+] Walkthrough of the education setting should be repeated at the beginning of the debrief session.

[+] Heuristic and evaluation criteria should be accessible at all times and visible during the debrief session.

Table 86: Workshop findings on e-learning evaluation protocol

6.8 Chapter Summary

This chapter has focused on the results from all three phases and all research elements within the study. The mixed methods exploratory design, and specifically the qualitative priority in the first two phases, led to a large volume of research findings. Due to this large volume, many results are presented in an abridged form in this chapter, but reference appendices where the exploratory findings are presented in richer detail and description. This chapter and this summary are structured accordingly:

1. The Phase 1 pilot findings,
2. The teacher and education expert feedback on the e-learning pedagogy,
3. Findings from student usage of the e-learning software prototype during Phase 1 and 2,

4. Phase 3 results,
5. E-learning evaluation protocol results.

The Phase 1 Pilot Findings - Phase 1 acted as a pilot study to set a stable foundation for the research, and identified the need for several changes in the research direction, including:

1. Preliminary positive feedback and direction on the research methods and experiment protocol for uptake in the subsequent phases.
2. The refocusing of the research away from two separate pedagogical strategies (one for computer science teaching and one for computer science e-learning software development) towards a single e-learning pedagogy for design.
3. Inclusion within the pedagogy of collaborative and social learning and hence the inclusion of heuristics related to collaborative learning environments.
4. The realisation that the development of quality e-learning software is a complex task and, considering the teacher audience, a more appropriate focus for the pedagogy is the definition of a set of heuristics that guide teachers (and instructional designers) to design e-learning software or evaluate existing software for inclusion in their teaching.

Teacher and education expert feedback on the e-learning pedagogy - The teacher and education expert evaluation and input into the e-learning pedagogy spanned all three phases, and included supplementary teacher feedback from the e-learning workshop in Phase 3. Ultimately, in Phase 3 the e-learning pedagogy was judged to be:

1. Appropriate for school pupils aged between 15 and 18-years old (Key Stage 4 and 5);
2. Appropriate to computer science and potentially other STEM subjects;
3. Offering comprehensive and balanced pedagogical coverage;
4. Appropriate for the teacher audience[34]; and
5. Feasible to be implemented in a high-school environment[35].

Findings from student usage of the e-learning software prototype during Phase 1 and 2 - The findings in this section are exploratory in nature, having been based on student usage of an iteratively evolving version of the e-learning software prototype; these findings were later triangulated with survey and focus group results, and grouped thematically:

1. **Usability and Navigation** – Broadly positive student response on usability and navigation, which gave feedback, direction and support to heuristics: 17, 19, 21 and 21.1.

[34] Although there remained some concern from one education expert that the relative time demands placed on teachers means that although the pedagogy is a valuable and rich resource, its relative length and potential complexity to implement may hinder it being put into practice.

[35] The pedagogy provides guidance on heuristics that may prove more challenging to be implemented in schools. However, there was some residual concern that the pedagogy does not explicitly consider the "*alien environment*" that can be encountered in some schools.

2. **Learning Styles and Multi-modal Learning** - Positive student response, which gave feedback, direction and support to heuristics 16, 16.1, 16.2, 16.3 and 16.4.
3. **Learning Object Ranking** - The learning object ranking between the two phases are not consistent. However, show some preference towards visual and active learning object types and consistent negative ranking for audio and collaborative activities. These findings gave feedback, direction and support to heuristics 4, 4.1, 6.2, 7, 9, 11, 16.1, 16.2, 17, 17.1 and 17.2.
4. **Understanding and the Zone of Proximal Development** - Positive student feedback that educational material was represented in a clear and understandable way and that there was no need to supplement the e-learning software with further textbook reading. In Phase2-Cycle2, students reported that educational material was at the right level, and assessment activities were at the right level or a little difficult. These findings gave feedback, direction and support to heuristics 1, 4.1, 7, 7.1, 8, 9, 10, 16, 16.1, 16.2, 16.3, 16.4, 17, 18, 19, 20 and 21.1.
5. **Visuals** - Positive student response that visual elements are important, and judged to be meaningful, engaging and support their understanding of the subject matter. However, there is a comparatively weaker student response on the aesthetic appeal of the visual elements. These findings gave feedback, direction and support to heuristics 16.1, 17, and 17.1.
6. **Text** – In spite of initial issues in Phase 1, overall, student response shows recognition that text material is important in supporting their understanding of subject matter. These findings gave feedback, direction and support to heuristics 16.3, 17, 17.1, 20.
7. **Activities and Active Learning** – Positive student response that the activity-based (interactive) components are engaging and support student understanding of subject matter. Overall, the students responded that the e-learning software prepared them for the assessment activities, and that the assessment activities encouraged them to think rather than recall from memory. These findings gave feedback, direction and support to heuristics 1,2, 4, 4.1, 5, 6.2, 7, 7.1, 14.3, 14.4, 15.1, and 16.4.
8. **Video** - In spite of the drop in ranking between Phase 1 and Phase 2-Cycle1, videos remain an important part of the e-learning software, and are a valuable tool in the support of visual modal preference (heuristic 16.1) and visualisation approaches.
9. **Computational Thinking** - Positive student response that the e-learning software helped them to understand what computational thinking is, but positive response progressively weakens between recognising computational thinking concepts and being able to use them. These findings gave feedback, direction and support to heuristics 6, 6.1, and 6.2.
10. **Collaborative Learning** - Collaborative learning was consistently ranked lowly by students, collaborative activities were underutilised by students, and received a mixed response on whether it supported their understanding of the subject matter. However, students understand at a conceptual level the reasons and value of collaborative activities, and the focus group responses were positive towards collaborative learning. It is theorised that the research and experiment design was not conducive to evaluating collaborative learning since it was primarily

in class, for a short period of time, and voluntary. These findings gave feedback and direction to heuristics 9, 11, 11.1, and 12.

11. **Audio** - Audio material was consistently ranked low by students, but its retention was requested on condition that the audio quality is good, a mute button is available, and that the e-learning software remains pedagogically effective even when audio is disabled. These findings gave feedback, direction and support to heuristics 16.2, 17, 17.1, 17.2, and 20.
12. **Authentic Learning vs Avoiding Overload** - There is pedagogical tension between the following - heuristics: 1: Use authentic educational material, examples and activities, and 18: Avoid adding learning content that does not directly support your instructional goal. The student preference was towards heuristic 1, and metacognitive decision-making was supported by the inclusion of a red "i" to indicate additional information that is non-examinable.
13. **Connectivism and the Web** - Findings support the moderate connectivist approach recommended in the pedagogy. Student showed understanding that a critical appraisal of the information found on the web is necessary; accordingly, they showed a weak preference towards the e-learning software since it is perceived to be accurate, comprehensive and reduces wasted time searching the web. By design, the e-learning software acts as a hub that links to other learning resources. These findings gave feedback, direction and support to heuristics 1.1, 11, and 12.
14. **Motivation** – Students responded positively regarding whether the e-learning software is more interesting than textbooks, that it can be used for independent study, and it has increased their overall enthusiasm and interest in computing. Overall IMMS results are consistent across Phase 1 and 2, at approximately 3.67 from 5. These findings gave feedback, direction and support to heuristics 1, 7, 13, 14, 14.1, 14.2, 14.3, and 14.4.
15. **Gamification** - The intrinsic aspects of gamification garnered a positive student response. The student response towards the extrinsic aspects of gamification is mixed with some trends towards the negative. However, it is theorised that limitations in the LMS implementation of gamification is a partial root cause. These findings gave feedback, direction and support to heuristics 15, 15.1, and 15.2.
16. **Recreating Books** - Students requested a more explicit structure in the e-learning software that mimics a traditional chapter format. In response, the e-learning software was divided into levels with learning objectives, learning material and review questions. These findings gave feedback, direction and support to heuristics 19, 21, and 21.1.

Phase 3 results - Phase 3 used a convergent parallel mixed methods design with a quantitative priority, and reported primarily on student perception and learning performance, based on hands-on usage of the e-learning software in class and for homework.

- **Student Perception of E-learning Software -** Student responses from the survey instrument (including VARK and IMMS instruments) are reported in summarised format in Table 46. Please refer there for a recap.

- **Student Learning Performance -** The average student learning performance and engagement with the e-learning software and CLE are reported in summarised format in Table 47. Please refer there for a recap.

E-learning Evaluation Protocol Results

1. **Phase 1 Pilot** - The e-learning design activity identified the need for an e-learning evaluation protocol to effectively assess the specific pedagogical coverage of e-learning software. This was then incorporated as a second research objective of this study.
2. **Phase2-Cycle2** - During Phase2-Cycle2, the e-learning evaluation protocol was reviewed by three education experts, who gave constructive feedback. This feedback did not structurally affect the evaluation procedure but was significant in defending decisions and approaches used in the protocol, and in documenting the protocol with enough detail and clarity for effective usage. Additionally, the e-learning evaluation protocol was piloted by the researcher. Piloting of the e-learning evaluation process confirmed that the overall structure of the protocol steps is functional; additionally, it helped to explain and support the feedback from the education experts by placing it into a more practical context.
3. **Phase 3** - Feedback on the Phase 3 e-learning evaluation protocol was provided by two education experts and a workshop, used as a vehicle to study the usage of the evaluation protocol. In Phase 3 the feedback from the education experts plateaued and was nominal. The workshop research findings are broadly positive, with some direction for future work, and are already reported in summarised format in Table 86. Please refer there for a recap

7 DISCUSSION

7.1 Chapter Brief

This chapter discusses and interprets the results from the three phases and the underlying research elements within this study. These elements are pulled together and interpreted in a holistic and cohesive discussion that briefly recaps the underlying problem domain, and then focuses on:

1. **Providing a Solution and Research Contribution**
    a. Proposing e-learning software as one part of the solution;
    b. Framing the status of e-learning software and the limitations of existing e-learning software in terms of their pedagogical foundations;
    c. Identifying a lack of research into high-school computing pedagogy;
    d. Identifying a lack of research into e-learning heuristics focused on pedagogy; and
    e. Identifying a lack of research into e-learning evaluation protocols focused on pedagogy.
2. **Discussing the Results of the Study**
    a. Discussing the theoretical evaluation of the e-learning pedagogy by education experts and teachers;
    b. Discussing the student usage of the e-learning prototype and how it informed the e-learning pedagogy; and
    c. Discussing the impact that student usage of the e-learning prototype had on learning performance.

7.2 Globalisation, Digital Ubiquity and the Need for a Strong IT Sector

This study reasserts the ubiquitous nature of digital technology that is driving what is predicted to be the fourth industrial revolution, in which a holistic ICT ecosystem will be tied into every aspect of our lives. Furthermore, digital technology fuelling globalisation has led many countries to take on national imperatives to build strong IT sectors that can drive their economies within the new global order. In the UK, the growing unmet demand for IT professionals focused a dissatisfied political spotlight on computing education in schools, which in turn led to far reaching reform.

The issue of whether these assertions were entirely valid: the exact role and importance of high-school computing education for the nation's supply of IT professionals; the steps taken by the Government, the Department for Education (DfE), and other influential stakeholders in bringing computing education out of crisis; and whether those steps have been effective, are not judged in this research. But they do serve as a backdrop for the research, and motivate this research's support for computing education and computer science teachers through the difficult transition from ICT to computer science. What is clear is that despite initiatives to redress the situation, in the past five years (up to the end of 2017), the strain placed on the high-school computing teachers has become more pronounced.

7.3 E-learning Software is Part of the Solution

This research does not contend that e-learning software is a solution for all the perceived challenges in high-school computing education in the UK. However, quality e-learning software can be used as an important tool to support teachers (especially those less confident with the computer science portion of the curriculum) with subject-specific material that is pedagogically sound, and can be used to inform their teaching methods. Furthermore, whilst the e-learning pedagogy is not intended to instruct teachers in good teaching practice, many of the teachers involved in this research have explicitly commented that it has positively informed their teaching.

Investment in, and the growth of, e-learning usage has been widely reported as one of the most rapidly expanding areas of education and training in industry, and to a good extent in schools. Several benefits are reported in terms of learning performance and motivation, serving both academically strong and weaker students. However, the basis of this research acknowledges that e-learning software is not a '*silver bullet*'[36]; there remains caution on the strength of the evidence regarding e-learning benefits, and concern still persists that what is delivered in terms of e-learning software can fall short, especially in terms of pedagogical usability and alignment with educational needs. It is this concern that lies at the core of this research; e-learning software can be a beneficial tool to teachers, but only if the content and pedagogical quality of the software is safeguarded. This can be achieved by defining a comprehensive set of pedagogical heuristics to guide teachers and instructional designers in designing and/or evaluating e-learning software for use in teaching. Additionally, teachers and other education stakeholders can be supported in selecting appropriate e-learning software via a rigorous e-learning evaluation protocol.

This research recognises that there are several factors that contribute towards successful e-learning, such as: usability; underlying infrastructure in schools and student homes; teacher readiness; level of student e-maturity; and level of school, vendor and parental support, etc. However, a targeted research focus is purposely given to an area of notable concern that is under-researched and has high impact: the underlying pedagogy of e-learning software.

There are a variety of texts on e-learning instructional design; in contrast, this research supplements existing literature by providing an accessible set of heuristics for e-learning pedagogy that focuses on, but is not restricted only to, high-school computer science. These heuristics are designed to communicate the essence of a wide body of pedagogical knowledge in an understandable and usable form to a teacher audience. The heuristics are proposed due to the persisting concerns that were previously outlined regarding e-learning pedagogical quality, and are necessary due to the scarcity of e-learning heuristics that give adequate focus to pedagogy. Additionally, where research has concentrated on e-learning

[36] A simple and seemingly magical solution to a complicated problem.

pedagogy it has focused on specific pedagogical aspects of e-learning, rather than a holistic pedagogy for e-learning. In contrast, this pedagogy considers the three dimensions of content, incentive and environment to ensure comprehensive coverage of how learners': interact with their external environment to stimulate learning; build meaning and understanding; and direct the requisite mental energy to support learning. At the time of writing (January 2018), this study had not identified an equivalent holistic set of heuristics focused on e-learning software for high-school computing.

As common practice, the defined pedagogical heuristics are dual purpose: to guide the pedagogical design of e-learning software, and to serve as the basis of a protocol to guide the evaluation of such software. Similar to e-learning heuristics, e-learning evaluation protocols have a historical bias that continues today, predisposed towards usability to the neglect of pedagogy. Whilst numerous researchers expound the need to assess the educational quality of e-learning systems, few have a concerted and detailed focus on the evaluation of pedagogy. Hence, this study attempts to redress this gap by having a detailed focus on pedagogical heuristics, and the evaluation of e-learning pedagogy and content quality. This focus is by design, but does not ignore the fact that there are other notable factors that contribute towards successful e-learning that must also be evaluated. Most notable amongst these factors is the evaluation of usability. It is therefore envisaged that the evaluation of pedagogy and content quality may not be the only evaluation carried out, but is a majority contributor towards the results of a wider set of evaluations.

This study has synthesised a robust protocol for evaluation steps based on existing best practice in evaluation. In addition, it is novel (and arguably unique) in that it is characterised by: support for both formative and summative evaluations; considers the educational setting for software usage; is defined at a detailed level; focuses on pedagogical and content quality (learning objectives) rather than usability issues; provides quantifiable results that can be used for comparative evaluations; and focuses on the reliability and validity of evaluation results. Considering these characteristics, the proposed e-learning evaluation protocol would have added significant value in recent evaluations of high-school computer science e-learning resources, previously discussed in section 2.3.3 (i.e. New Zealand, Morocco and Australia). These evaluations were coloured by limitations, such as: neglecting pedagogical evaluation entirely; giving limited coverage of pedagogical principles; giving limited detail in the evaluation criteria, thereby leaving them open to interpretation; coarsely defined quantitative measurement and results; and a lack of an encompassing protocol to reliably guide the evaluation. These recent studies reflect a need for the evaluation of digital education resources; but also, the inherent limitations of each of the evaluations reflect the need for a rigorously defined evaluation protocol focused on pedagogy. Considering, the UK's (Waite 2017) recent call to evaluate the pedagogical foundation of their high-school digital education resources, this need is likely to continue.

7.4 Contribution to a Small Body of Research and Establishing Research Rigour

This study offers a contribution to the small body of research into high-school computing pedagogy. The literature classification from Sentance and Selby (2015) of computing education research between 2005 and 2014 identified 2,225 papers, of which only 66 were focused on school age students or teachers, and pedagogy. Supporting findings are also identified by the recent pedagogy literature review (Waite 2017) commissioned by the Royal Society , which concentrates on research in the past ten years and initially identified over 700 papers, which were eventually reduced to 86 papers focused on computing pedagogy relevant to schools.

Further analysis by this study of a version of Sentance and Selby's literature classification, gives further evidence of this under-researched area (reported in Table 2), examples include:

1. Only two papers had a major theme of pedagogy for computing education in schools and a minor theme of e-learning.
2. Of the 58 papers related to pedagogy for computing education in schools, none gave a holistic view of pedagogy. Instead, their focus was on narrow aspects of pedagogy.
3. Of the 89 papers with a major theme of e-learning, one paper focused on pedagogical patterns, and one focused on pedagogy with e-learning; however, the latter focused specifically on pedagogy for virtual classrooms.
4. Four papers had a major theme of e-learning and a minor theme of school age students or teachers, all of which focused on specific components of e-learning (i.e. learning objectives, e-portfolios, algorithms, and outreach).
5. Four papers had a major theme of e-learning and a minor theme of pedagogy, none of which took a holistic view towards pedagogy for e-learning.

These findings are also confirmed by the literature review from this study, which did not identify comparable research to define a holist set of pedagogical heuristics for e-learning. The closest conceptual alignment with the objectives of this study is Dabbagh (2005) who offers a theory-based framework for e-learning design, but this framework is not specified in detail and is limited to a theoretical perspective.

The literature review from this study and the analysis of recent well-reputed literature reviews give a strong indication that research into a comprehensive and holistic set of pedagogical heuristics for teaching, or the design of e-learning software for high-school computer science, is currently a severely under-researched area. This is also echoed in the calls by the Royal Society for research in high-school computing pedagogy.

This study also contributes a measure of research rigour to the small body of research into high-school computing pedagogy. Condie and Munro (2007), Means et al. (2009), Livingstone (2012), and Kim et al. (2014) take a somewhat critical view of the evidence of improved pupil attainment through e-learning/ICT; they contend that much of the evidence is taken from small-scale studies lacking the rigour and scale by which generalisations can be drawn. More recently, Sentance and Selby (2015), Waite (2017), and Crick (2017) reiterate the same concerns, that most of the existing research is not conducted in a classroom context, and lacks methodological rigour relating to sampling, sample size, statistical significance and claimed impacts.

In contrast, the mixed methods research design used in this study offers a highly rigorous research design that has involved five education experts, six teachers (excluding the 13 teachers who joined the Phase 3 workshop), and 76 students in total.

The phased mixed methods design and the use of action research ensured that what was theorised was assessed in a realistic school context. In addition, the research design inherently supported the iterative development of the research and multiple points of triangulation to validate research findings. The approaches towards trustworthiness (credibility, transferability, dependability, and confirmability), and internal validity, external validity (generalisable), reliability and objectivity are discussed at length in Chapter Three; as are the validity and reliability of the instruments used in the study. Findings are presented regards the reliability of the IMMS results and the reliability (alternate form and internal consistency) of the survey instrument. Quantitative results for Phase 3 are presented with parametric tests and, where appropriate, re-confirmed using bootstrapping and non-parametric tests.

Most importantly, the qualitative findings for the exploratory phases (Phase 1 and 2) are confirmed and generalised by Phase 3, using a larger student sample.

7.5 International Contribution

This study primarily focuses on UK high-school computing education. However, the challenges faced in the UK are by no means unique, and the transition of high-school curriculums to a more computer science focus has been undertaken by several countries. Section 2.2.6 reflects that the USA, Israel, Germany, UK, Austria, Slovakia, Switzerland, Italy, Lithuania, and Poland are active in varying degrees in this research area. Also, that the US, New Zealand, Australia, Israel, Germany, France, Italy, Sweden and India are all in varying stage of similar initiatives to give prominence to their high-school computer science curriculums. Arguably, countries such as the US, Israel, Russia, Australia and New Zealand have made significant progress in establishing their high-school computer science curriculums. The computer science curriculums in the aforementioned countries may have some underlying differences, but it follows that the objectives of this research are broadly transferable to the countries listed in this section, and more. This is directly exemplified by clear patterns of usage of technical teaching resources for the computing curriculums in the US, Australia, New Zealand and Morocco.

7.6 Synthesising an E-learning Pedagogy

The pilot phase of this study served its purpose well in giving a more realistic and directed focus to the research. The outset of this research focused on the delivery of two pedagogies: one for computer science teaching and one for computer science e-learning software development. In retrospect, there was an element of naivety in these objectives that the pilot quickly remedied. Considering the idiosyncrasies and challenges faced by teachers every day, there is a credibility gap for an academic with limited teaching experience to propose a pedagogy for teachers. However, with that in mind, the teacher evaluations of the e-learning pedagogy did not reflect this point; in fact, they were very encouraging and reported that the pedagogy was used to inform their own teaching practice.

"*Reading through the report provided, I find myself inadvertently using a number of the heuristics. All of the heuristics seem to cover every single aspect of a teaching method*." [Teacher 2]

"*Extremely clear and very well structured. As I have mentioned earlier very detailed description and I have already started to evaluate my teaching… Truly exceptional research and since I am currently exploring more about computational thinking I personally found this as a very useful addition to my other books and documents on this subject*." [Teacher 3]

"*Overall, this pedagogy document is great learning for me and I have learnt a lot by just reading it. I will be sharing this with my team (if you agree) and will be using your research in my teaching practice*." [Teacher 4]

In addition, the pilot identified that a pedagogy for e-learning **development** targeted to a teacher audience was not a realistic proposition. A more realistic objective was to concentrate on teachers' existing experience in teaching and strengths in pedagogy, to support them in designing or evaluating e-learning software.

The original focus of the research was purely on creating e-learning software; however, it became clear that e-learning software is constrained when treated as an isolated entity, and that significant educational value can potentially be gained by integrating the e-learning software within a CLE. Hence, the pedagogy was extended to consider collaborative and social learning.

Finally, the pilot identified the need for an e-learning evaluation protocol; hence a secondary research objective was added to the study. Overall, the pilot was instrumental in focusing the study towards pedagogical heuristics for the design or evaluation of e-learning software (including CLE), and an associated evaluation protocol. Both artefacts remain targeted to a teacher or instructional designer audience.

The resulting pedagogy aimed to be comprehensive and holistic in its coverage of learning; it rejects the learning theory debate and focuses on commonality and areas of interaction between the chosen theories. It synthesises an overwhelming body of knowledge in learning theories into a set of heuristics that are intended to be succinct and accessible to teachers. The pedagogy is intended as a toolkit, which is not reductionist; it does not prescribe when to use particular heuristics, this remains in the teacher's control and judgement. However, it does provide detailed information on design criteria, potential benefits, how the heuristics interrelate, and potential challenges in implementation, all of which inform the teacher's judgement of how and when a heuristic should be used.

The iterative evaluation of the e-learning pedagogy by education experts and teachers supported the development of a pedagogy that is characterised as:

Appropriate for school pupils aged between 15 and 18 years old: Throughout the evaluation iterations, the education experts and teachers confirmed the heuristics appropriateness for 15 to 18-year olds. Furthermore, an analysis of the UK Department for Education's curriculum for computing showed a strong alignment between the heuristics and learning objectives for both Key Stage 4 and 5.

Appropriate to Computer Science: There is broad confirmation from education experts and teachers that the heuristics are appropriate for computer science education, support underlying skills important to computer science, and potentially can be used to support other STEM subjects.

"*The heuristics are appropriate for Computer Science education (as well as other STEM subjects). Many of the heuristics, especially the ones related to problem solving are important for fields such as computer science where students are expected to develop skills in problem identification, analysis, solution design etc. as well as evaluation skills drawing on supportive evidence.* "[Education Expert 2]

"*Having in mind my previous answer I would like to add that incorporating heuristics in Computer science or more specifically any STEM type of subject could greatly benefit students, subjects that require or rely on problem solving or an experience, and also being able to actually view something happening can motivate and increase likelihood of a more memorable lesson*." [Teacher 2]

"*I strongly agree Computer Science education focuses more on Problem based learning and prompt reflective practice to support learning. It is very important to build foundation on Computational thinking before using it*." [Teacher 3]

Balanced pedagogical coverage: There is broad confirmation from education experts and teachers that the heuristics are comprehensive and offer a balance pedagogical coverage. In Phase 1, there was cautionary comment on the sub-heuristic that static illustrations can be better than animations; this heuristic was eventually removed. Overall, there was limited feedback to include additional heuristics; in Phase 1 there was expert feedback to give more focus on engagement and gamification, which was followed by the addition of relevant heuristics in Phase2-Cycle1. In Phase2-Cycle2 there was teacher comment on the educational value of learning from mistakes. This was not covered in a discrete heuristic, but already existed in the pedagogy as design criteria in other heuristics.

"*There is a balanced pedagogical coverage with appropriate emphasis on overarching educational theories and key concepts. These are well linked to strategies that guide teaching practice in computer science*." [Education Expert 3]

Appropriate for teacher audience: A significant focus of the pedagogy development was in ensuring it is appropriate and adds educational value to the primary audience: teachers. This involved: multiple iterations of re-phrasing and re-sequencing of heuristic titles, descriptions and criteria; rationalising the heuristics and underlying criteria to shorten the document to a manageable length; focusing on appropriate terminology and including a glossary; including sections on educational benefits, potential challenges and the interrelationship between heuristics; and adding visual representations of interrelationships and potential educational benefits. By Phase2-Cycle2, this had led to a pedagogy document that was vastly improved and overall was well received; but the scale of the pedagogy and the endeavour needed to fully utilise it still left some residual concern.

"*This version of the pedagogy document is much better than the previous version, with good reading flow and structured organisation. The way each pedagogy is presented (the structure of each section) is beneficial to a novice reader, since they can get familiar with the concepts through the Description, look at the Design Evaluation Criteria and also be informed of the Educational Benefits and Potential Challenges.*" [Education Expert2]

"*Extremely clear and very well structured. As I have mentioned earlier very detailed description... Clear references to the different heuristic technique made it easier for me to look at the different approaches… I could clearly see education benefits of each heuristic approach has been clearly explained*." [Teacher3]

"*Document is very well structured and has a clear structure and contents page. Research is very clear and it has a strong connection with all the activities carried out during school activities*." [Teacher 4]

"*This is certainly a valuable and rich resource for teachers, however the complexity and length might prevent some to fully utilise and put into practice. E.g. a school would need a series of staff meetings to discuss this document and many mentoring sessions will be required for teams of professionals to use. Similarly, for designers this is a useful resource, yet it requires time and effort to be understood*." [Education Expert 3]

A noteworthy point of triangulation occurred in the workshop; the evaluators (in-service teachers) were asked to give high-level feedback on the heuristics, based on the training they had received in the workshop (without access to the pedagogy document). One evaluator offered the following feedback on the heuristics:

"*There are a lot of them, and they sometimes compete or contradict each other. This is fine, but busy teachers are not going to be able to remember the full set. Perhaps a condensed version, including the most important/beneficial heuristics, or a flowchart that can be followed easily, would make them more useful*." [Evaluator 1]

This feedback is particularly insightful since it was identified in previous research phases during the teacher and expert evaluations of the e-learning pedagogy document, and was implemented in the document by the addition of a heuristic summary table, an educational benefits matrix, a heuristic relationship diagram and a detailed heuristic relationship matrix.

Feasible to be implemented in a high-school environment: An area of critical importance is the feasibility of implementing the heuristics within a school environment. In Phase 1, Education Expert 1 introduced a note of concern:

"*The school and the classroom is a very "irrational" and alien place...but it is the environment we are designing for*." [Education Expert 1]

The pedagogy is designed as a toolkit in which heuristics that can be selected based on the specific learning material, intended audience and intended learning objectives. In this respect, the majority of the heuristics can be implemented in a high-school environment without difficulty. However, some of the heuristics have a bit more challenge to be implemented in a high-school; these challenges are also documented and addressed in the pedagogy. In this respect, there was broad confirmation from the education experts of the pedagogy's feasibility for high-schools.

"*The heuristics do not take into consideration of the broader school curriculum, ethos, timetable and goals because this is not part of this study. Overall, the heuristics as they stand could be implemented in a high school setting*." [Education Expert 3]

A weaker, more neutral stance was taken by some teachers, which seems to be more reflective of the challenges in schools rather than shortcomings in the heuristics. Teacher 2 gave a balanced response reflecting that *"any addition to the syllabus can be both good and bad".* However, that incorporating such heuristics into high schools *"can certainly influence students learning and teaching in a positive manner".* The challenge is that despite the potential benefits, the transition may not necessarily be smooth. Teacher 3 offered some optimism, but again reverted to the reality in schools:

"I could evidence that many of the heuristics are already implemented in high school environment. All schools focus on results oriented learning so even though they implement many of the suggested heuristics. I think new learning happens only when students carry out projects on their own or practical activities.

There is very little time provided for student content which deepens learning, and this is one of the key areas being ignored when considering why progression of students taking computer science from KS4 to KS5 is not 100%." [Teacher3]

An interesting point is that only one teacher evaluated the pedagogy and also used the e-learning software with his students. This teacher's response on whether the pedagogy is feasible to be implemented in schools is markedly different:

"*Yes, as students have made massive progress and learnt a lot by following the e-learning software based on pedagogy*." [Teacher 4]

The overriding conclusion is that when designing e-learning software or evaluating software for use in schools, the heuristics that will be applied must also consider the reality of the school context in which the e-learning software will be applied.

By Phase 3, there were indicators that the e-learning pedagogy had reached a mature state, this is evidenced by the plateau in feedback, which was overwhelmingly positive. This was further supported by the broad consensus in the teacher workshop that the heuristics were appropriate for: 15 to 18-year olds (Key Stages 4 & 5); computer science education; and had comprehensive and balanced pedagogical coverage[37].

[37] This is with the exception of one evaluator.

7.7 Pedagogy Feedback as Evidenced by Usage of E-learning Software

The theoretical synthesis and evaluation of the e-learning pedagogical heuristics was also informed by a practical implementation in which students used e-learning software designed in adherence with the pedagogy.

As previously recognised, **usability** is important in software, and a significant prerequisite in e-learning software, since its absence can hinder the learning process. The e-learning pedagogy presupposes usability in the software and does not provide usability heuristics; however, there are a number of heuristics that touch upon usability. These are:

- 17: Integrate words and graphics together, instead of words alone.
- 19: Optimise essential processing by segmenting learning material and providing pre-training.
- 21: Provide restricted navigational control in the e-learning software.
- 21.1: Provide consistent navigational elements and signposts for learning.

Considering the students' age, the pedagogy proposes restricted navigational control, segmenting of learning, the provision of pre-training, and sign-posting of learning; this culminates in a relatively structured and stable learning environment. However, this is balanced with the learners need to feel in control of the actual learning experience. These aspects were well received in Phase 1 and 2, which reported broadly positive findings on the ease of use, usability, and clarity of the e-learning software. Although, there were some refinements to be made to the instructions, learning object sign-posts and the structuring of the pre-training videos. Phase 3 offered confirmatory results in that almost all survey instrument responses related to usability had a median student response of **agree (4).**

An important factor to consider is that Tier-2 medium effect correlations of students' perception of usability (Question 4A) and reliability (Question 4J) were linked to %Post-Test results. Causality is theorised that students who perceive the e-learning software to be usable and reliable are free (unhindered by usability issues) to focus on the learning material, and therefore have improved performance.

One potential area of discontinuity between the exploratory phases and Phase 3 is that the reliability of the e-learning software received comparatively weaker findings in Phase 1 and 2, but received a median student response of **agree (4)** in Phase 3. However, a closer look at some of the underlying questions on reliability in Phase 3 confirmed the findings in Phase 1 and 2 since the median student response showed **neither agreement nor disagreement (3)** with three metrics focused on reliability. Additionally, in Phase 3 a small number of responses to open questions did comment on bugs in the software.

Heuristics related to **learning styles and multi-modal learning** are well-evidenced in all three phases of the study:

- 16: Use multi-modal learning approaches

- 16.1: Support visual modal preference.
- 16.2: Support aural modal preference.
- 16.3: Support read-write modal preference.
- 16.4: Support kinaesthetic modal preference.

Phase 1 and 2 show comparative balance between the students VARK modalities and positive student feedback on the use of varying methods to represent the same educational concepts. Even the initial misstep in Phase 1, of the researcher not managing his dominant read-write modality, and creating e-learning software with a text overload, provided inverse confirmation for multi-modal learning. Phase 3 offers confirmatory results in that parametric and non-parametric tests show comparative balance between each of the four modalities, with the exception of a statistically significant difference between visual and kinaesthetic modalities. Phase 3 also offered positive student feedback with a median response of **agree (4)** with the statement *"The use of different methods to represent the same learning content helped my understanding."* Finally, a further weakly positive result for multi-modal learning is provided by the median student response of **neither agree nor disagree (3)** with the statement "*The use of different methods to represent the same learning content made me feel overloaded.*"

The correlation analysis identified a fascinating VARK result that is challenging to interpret; a Tier-2 weak effect negative correlation was identified between aural modality and %Post-Test. Causality could potentially be that the audio implementation in the e-learning software was unsatisfactory and hence negatively impacted the learning performance of those with higher aural modalities. A more far-reaching potential cause is that those with a higher aural modality are not so well served by multi-modal learning, suffering impact to their learning performance.

Managing **cognitive load** is a central tenet of the pedagogy; it is recognised that there is a tension between the cognitive load placed on students and some of the heuristics with constructivist, multi-modal and connectivist foundations. The importance of managing cognitive load is clearly shown in Phase 3, in the correlation analysis which reflected a Tier-2 medium negative correlation between the students' feeling of being overloaded by multi-modal approaches and %Post-Test results. In addition, a Tier-1 (statistically significant) medium negative correlation can also be seen with %Change. Broadly speaking, the students' learning performance is negatively correlated with any perception of being overloaded by the e-learning software (and vice versa). Although, it is reminded that the students' median response reflected that they did not feel overloaded.

The pedagogy cautions that the implementation of the following heuristics needs to be considered in light of the additional cognitive load they place:

- 1: Use authentic educational material, examples and activities.
- 1.1: Ensure the currency of learning material.
- 3: Make expert and learner thinking processes explicit.
- 4: Use problem-based learning (PBL) to facilitate learning.

- 5: Integrate learning into long-term memory by using authentic examples, and non-trivial practice and problems.
- 6.2: Exemplify computational thinking in problem-solving activities.
- 12: Develop and nurture networks to support learning.
- 13: Use constructivist approaches to increase intrinsic motivation in the learner.
- 16: Use multi-modal learning approaches.

Furthermore, the following heuristics can be used to manage and reduce cognitive load:

- 4.1: Use worked examples to support problem-based learning.
- 6.1: Build a foundation for computational thinking.
- 8: Provide scaffolding to advance learning progress.
- 17: Integrate words and graphics together, instead of words alone.
- 17.1: Apply contiguity by aligning words (audio or screen text) with corresponding graphics.
- 18: Avoid adding learning content that does not directly support your instructional goal.
- 19: Optimise essential processing by segmenting learning material and providing pre-training.
- 20: Use a conversational style in screen text and audio narration.
- 21: Provide restricted navigational control in the e-learning software.
- 21.1: Provide consistent navigational elements and signposts for learning.

As discussed earlier in relation to usability, the relatively structured and stable learning environment proposed in heuristics 17, 19, 21, and 21.1 was well received by students across all phases. In addition, it also has a contributing benefit in helping to reduce cognitive load. Heuristics 19, 21, and 21.1 were also studied and well received by students in Phase 2; with the students request for a more explicit structure in the e-learning software, in particular in mimicking a traditional chapter format, with chapter learning objectives, learning material, review questions, and finally a learning summary. Again, this approach has contributed benefits towards reducing cognitive load. It should be noted though, this was not explicitly measured in Phase 3, hence was not confirmed using statistical tests.

A key area in managing cognitive load is the tension between authentic learning (Heuristic 1) and avoiding learning content that does not directly support the instructional goals (Heuristic 18). In Phase 2, students gave positive feedback in preference of Heuristic 1: "*Use authentic educational material, examples and activities*" and the inclusion of learning material that is not directly examinable within the curriculum, thereby increasing the cognitive load placed on them. However, to support their meta-cognitive processes, such content was flagged with a red "i" icon, to help in their decision on whether to review the learning material. It should be noted that although well received by the students; there was some question on whether the red "i" icon accurately communicated to students that the material was *"extend your knowledge"* material.

Phase 3 offered confirmatory results in that the median student response was **agree (4)** that the extend your knowledge material helped students to understand the subject matter. However, this result is weakened to some extent in that *"extend your knowledge"* material was ranked last from the ten learning object types, both in terms of perceived benefit to learning and perceived influence on interest and enthusiasm. Additional, confirmatory evidence is reflected in the comparatively high IMMS Relevance metric, with a median response of 3.29, which is between moderately true and mostly true.

The pedagogy gives focus to the communication of learning material in a **clear and understandable** way and support to the social constructivist principle of the **Zone of Proximal Development,** in which students are challenged just beyond their individual unassisted abilities. Clarity and understanding are provided in the following heuristics:

- 16: Use multi-modal learning approaches.
- 16.1: Support visual modal preference.
- 16.2: Support aural modal preference.
- 16.3: Support read-write modal preference.
- 16.4: Support kinaesthetic modal preference.
- 17: Integrate words and graphics together, instead of words alone.
- 18: Avoid adding learning content that does not directly support your instructional goal.
- 19: Optimise essential processing by segmenting learning material and providing pre-training.
- 20: Use a conversational style in screen text and audio narration.
- 21.1: Provide consistent navigational elements and signposts for learning.

In Phase 1 and 2, there was positive student feedback that the educational material was represented in a clear and understandable way, and that overall there was no need to supplement the e-learning software with further textbook reading. In Phase 3, this is confirmed with a median student response of **agree (4)** that the e-learning software was represented in a clear and understandable way. But only weakly corroborated with a median student response of **neither agree nor disagree (3)** on whether the students supplemented, or needed to supplement, the learning material with further textbook reading or teacher support. The Phase 3 results indicate that, despite the e-learning software being clear and understandable, a significant number (almost half) of the students would require further support. This is not interpreted as a negative result since the e-learning software is not proposed to replace teachers or to be used as an isolated learning resource. The pedagogy in keeping with connectivist and social learning principles proposes that e-learning software should link to other learning nodes, and a learning community in which the students can gain further support and scaffolding.

Challenging students in accordance with the ZPD is provided in the following heuristics:

- 1: Use authentic educational material, examples and activities.
- 4.1: Use worked examples to support problem-based learning.
- 7: Distribute well-designed practice activities across the lesson to support learning.
- 7.1: Provide explanatory feedback to practice activities to promote learning.
- 8: Provide scaffolding to advance learning progress.
- 9: Use social-interaction to increase learning and promote higher-order thinking.

- 10: Engage learners in a challenge; target learning towards the zone of proximal development (ZPD).

Phase 1 and 2 gave indicators that the students remain cognisant that this was a voluntary research study, hence the level of effort and focus on learning material and passing quizzes is curbed. In Phase 3, the tighter integration with the students' in-school lessons diminishes this factor, but it is likely that it remains a factor to some extent. Phase-2-Cycle2 also gave practical evidence of the importance of question design within the overall instructional design, this feedback was incorporated in the Phase 3 software. The pedagogy itself does not go to the level of detail of discussing question design; although, several of the heuristics for e-learning software can be used to inform question design.

In Phase 1 and 2, the students perceive the difficulty level of the e-learning content to be split between being at the right level and a little difficult, although the trend in Phase 2 was towards being at the right level. In addition, the students perceived the difficulty level of the assessment activities to be split between being at the right level and a little difficult, although the trend in Phase 2 was towards being a little difficult. In Phase 3, the median student response showed the difficulty level of the learning material, practice activities and quiz questions to be **at the right level (3).** Additionally, the median student response showed **agreement (4)** that the e-learning software had prepared them for the quiz questions.

Overall, the findings from Phases 1 to 3 indicate that the implementation of the e-learning software gave weak support for the ZPD. This was explained in more detail in the teacher workshop; in evaluating the Level 3 Orange software, multiple evaluators commented that the e-learning software supported progressive challenge that was appropriate for the average student, but may not be so appropriate for weaker or high performing students. This reflects that heuristic 10 guideline 5: "*Provide learning content and activities that adapt to the learner's current abilities and progress*", is particularly important and may require greater emphasis in the pedagogy.

A noteworthy factor in the instructional design of e-learning software, and in particular in the selection of which learning objects to use in communicating learning material, is that there is no consistent preference in what learning objects students perceive to benefit their learning. Phase 1, Phase2-Cycle1 and Phase 3 all had different rankings for the learning object types. However, one clear trend was that audio and collaborative activities were ranked poorly (last or close to last) in all three rankings. In Phase 3, audio, collaborative learning and extended knowledge were ranked in the last spots, both in perceived benefit to learning and perceived influence on interest and enthusiasm. However, in Phase 3, the students reported a median response of **agree (4)** that all learning objects, with the exception of audio, helped them understand the subject matter. In this respect, the median response is quite a blunt analysis; in contrast a ranking of the mean averages gave a closer alignment with the Phase 3 learning benefit ranking. However, the overriding conclusion remains: there is inconclusive evidence to support a preference towards particular learning object types; their use must be judged in the context of the learning material, and a balanced multi-modal delivery.

Although, this research does not offer any conclusion on students' preference towards learning object types, the pedagogy does advocate **activities and active learning**; in this respect we consider problem-solving, practice activities, quizzes, games and simulations. Phase 1 and 2 offered strong positive support that activity-based (interactive) components support student understanding of subject matter.

"*I mostly like the interactivity of the software and the fact that I am able to solve examples closely linked to real life situations*." [Student 5]

"*It is much better as it is interactive, it has some bugs though.*" [Student 16]

"*Games/Interactive components are really engaging. Videos and animations are an effective way of learning something. Sense of accomplishment when you find the correct answer is satisfying*." [Student 14]

"*The assessments summarised the content and connected different parts to each other, therefore making it more interesting as I needed to be more creative*." [Student18]

The pedagogy's focus on activities and active learning, is provided in the following heuristics:

- 1: Use authentic educational material, examples and activities.
- 2: Prompt reflective practice to support learning.
- 4: Use problem-based learning (PBL) to facilitate learning.
- 4.1: Use worked examples to support problem-based learning.
- 5: Integrate learning into long-term memory by using authentic examples, and non-trivial practice and problems.
- 6.2: Exemplify computational thinking in problem-solving activities.
- 7: Distribute well-designed practice activities across the lesson to support learning.
- 7.1: Provide explanatory feedback to practice activities to promote learning.
- 14.3: Build "Confidence" to increase learner motivation (guidelines-2 and -3).
- 14.4: Build "Satisfaction" to increase learner motivation (guideline-1).
- 15.1: Integrate gamification elements tightly within existing learning processes.
- 16.4: Support kinaesthetic modal preference.

Phase 1 offered support and Phase 2 offered strong positive support that the activity-based (interactive) components of the e-learning software are engaging.

Student perception of activity-based (interactive) components was not measured explicitly in the Phase 3 survey instrument; however, it was partially confirmed, since the students' median response on whether practice activities and quiz questions helped them understand the subject matter was **agree (4)**.

Phase 1 and 2 also offered strong positive feedback that the assessment activities in e-learning software encouraged them to think, and work through problems, instead of recounting from memory. However, there is partially divergent feedback in Phase2-Cycle2, where students agreed that the e-learning software also encouraged them to recall previous knowledge to answer the questions. The students' perception of these aspects was not measured in Phase 3.

The e-learning pedagogy integrates **connectivist principles** in the following heuristics:

- 1.1: Ensure the currency of learning material.
- 11: Use collaborative learning activities.
- 12: Develop and nurture networks to support learning.

The investigation of connectivism and the web was carried out in Phase 1 and Phase 2-Cycle1, and showed students to be intelligent and articulate in their response. The students reported that a critical appraisal of the information found on the web is necessary since the source and quality of information may be unreliable. This factor was also reported by Teacher 2 in Phase2-Cycle1:

"*Students today are bombarded with sources of information, but actually having the ability to distinguish what is most helpful and to actually be able to choose what tool or resource to use may be a challenge by itself*." [Teacher 2]

This concern is addressed in heuristic 12, which proposes a moderate connectivist approach in which the e-learning software acts as a focal point that recommends other learning resources to the students. Heuristic 12 also discusses in the Potential Challenges section that the teacher should now reduce their role of presenting learning material and readdress this focus towards teaching students' critical thinking and metacognitive skills for them to see connections between fields, ideas and concepts, and to critically evaluate the learning material that they find.

The findings in Phase 1 and Phase 2-Cycle1 showed that students have a weak preference towards the e-learning software compared to using the web for their subject learning; although the findings in Phase 2-Cycle1 were more polarised. Overall, the students perceived the e-learning software to be comprehensive and preferred the structure of having one place to learn from. Students wished to avoid the wasted time in searching the web and evaluating whether the information they found is correct, which is addressed by the e-learning software linking to other pre-vetted resources. Phase 1 student responses included:

"*I believe the E-learned software has everything I need, hence not requiring any other information that I must know to be obtained by the internet.*" [Student 4]

"*Through the use of an E-Learning software, I can use the Web as well, where the links to videos and blogs will be included in the software*." [Student 2]

"*Often on the Internet, details are mostly vague and one does not fully understand what he/she was looking to learn.*" [Student 5]

"*They are different things. on the internet you can get easily immediately the information you want and learn what you want. and in the E-Learning software IF you find what you want there is detailed reliable information*." [Student 6]

Phase 2-Cycle1 student responses included:

"*because I feel more independent as a learner when I search the information, I want to know on my own and I don't like the information to be brought by someone else*" [Student 25]

"*The internet: contains more information is easier to search through*." [Student 13]

"*you have all the information collected in one source and the it is all checked and reliable when on the internet you might not find what you want*." [Student 17]

"*The E-Learning software has activities and features that are much more engaging than looking up information on the Web. The Web sometimes contains sites with wrong information, so the E-Learning software would be a much more reliable and easy source of information*." [Student 14]

"*The E-Learning software has everything in one place, so I don't need to search the whole internet for all of the different subjects separately, which helps me save quite a lot of time*." [Student 18]

As per the research design, Phase 3 did not secure qualitative findings in this area; however, the quantitative results are aligned with previous phases in that the median student response is **neither agree nor disagree (3)**, with the statement *"I would prefer using the Internet and the Web to support my learning of the computing subject rather than this E-Learning software."*

A critical area within learning and within the pedagogy is **motivation**; the implementation of the e-learning software and associated student usage of the software showed modestly positive findings for the following heuristics:

- 1: Use authentic educational material, examples and activities.
- 7: Distribute well-designed practice activities across the lesson to support learning.
- 13: Use constructivist approaches to increase intrinsic motivation in the learner.
- 14: Use the concepts of Attention, Relevance, Confidence and Satisfaction (ARCS) to attain and sustain learner motivation.
- 14.1: Use "Attention" grabbing strategies to increase learner motivation.
- 14.2: Explain the "Relevance" of the learning material to increase motivation.
- 14.3: Build "Confidence" to increase learner motivation.
- 14.4: Build "Satisfaction" to increase learner motivation.

Phase 1 and 2 showed broadly positive student feedback that: it is more interesting to use the e-learning software to learn computing than the textbooks; the students could use the e-learning software for independent study; and the e-learning software had increased the students' overall enthusiasm and interest in computing. The first statement is weakly confirmed in Phase 3, since the median response was **neither agree nor disagree (3)** with the statement *"It is more interesting to use the E-Learning software to learn Computing than the textbooks."* However, the removal of four outliers improved the median student response to **agree (4).** Further, confirmatory evidence is provided in Phase 3, since the median student response to the second and third statements was **agree (4).**

The IMMS results in Phase 1 and 2 are also modestly positive since the overall IMMS mean results are consistent across Phase 1 and 2, at approximately 3.67[38] from 5; this is between **Moderately True (3)** and **Mostly True (4)**. In each version of the e-learning software, a concerted effort was made to use motivational approaches; Phase 2-Cycle1 focused on ARCS Motivational approaches and Cycle 2 focused on gamification. Therefore, the stability in overall IMMS values could potentially be viewed as discouraging. However, this needs to be considered within the context that many of the aspects of the software remain unchanged between versions, and the student participants also remain the same; hence, some of the novelty and motivation value is lost. By Phase2-Cycle2, three students had used the software three times, and two students had used it twice. It is therefore not a surprise that IMMS results remained stable. The Phase 3 IMMS results are broadly aligned with Phases 1 and 2, although comparatively weaker in that the IMMS Overall result is (Mdn=3.11, M=3.15 SD=0.57) as compared to mean of 3.67 in Phases 1 and 2. There are no published threshold values of what IMMS results motivational e-learning software should secure; therefore, this research postulates that results between Moderately True (3) and Mostly True (4) are satisfactory with room for improvement.

An interesting factor identified in Phase 3 is that the e-learning software's treatment of the four areas of motivation are perceived by students to be comparatively balanced, with the exception of Student Attention (Mdn=3.00, M=3.03 SD=0.54) and Student Relevance (Mdn=3.29, M=3.24 SD=0.71), which showed a statistically significant difference. In real terms, the difference is likely to be negligible and simply indicates that the software was slightly less effective in grabbing the students' attention in comparison to attuning to the students' personal relevance.

Noteworthy findings were identified by the correlation analysis in Phase 3; a correlation link between IMMS results and learning performance was not established; however, correlation between IMMS results and the time students devoted to the e-learning software was established.

A statistically significant medium effect correlation between student IMMS overall and Level-2 time was identified, and multiple Tier-2[39] medium effect correlations were identified between:

- Student Relevance and Level-2 time
- Student Relevance and Level-3 and -4 combined time
- Student Satisfaction and Level-3 time
- Student Satisfaction and Level-3 and -4 combined time
- Student IMMS Overall and Level-3 and -4 combined time

[38] Phase 1 IMMS was 3.65, in Phase2-Cycle1 it was 3.68, and in Phase2-Cycle2 it was 3.67.

[39] Tier 2: A correlation effect of ±.1 or more, and Bootstrap Confidence Interval (CI) does not cross over 0 threshold (i.e. CI is between -.09 and 1 or .09 and -1)

Causality is theorised that higher IMMS results in relevance, satisfaction and IMMS overall reflect a higher student motivation, and that motivation leads to students willing to devote more time to the e-learning software.

Gamification is also employed within the pedagogy and the associated e-learning software as a motivational aid. Gamification is incorporated into the e-learning pedagogy in the following heuristics:

- 15: Use gamification to increase motivation and learning performance.
- 15.1: Integrate gamification elements tightly within existing learning processes.
- 15.2: Build extrinsic gamification elements on top of existing learning processes.

Intrinsic aspects of gamification defined in heuristic 15.1 were already inherently part of the e-learning software from Phase 1, and are positively received. In Phase 2-Cycle 2, the extrinsic motivational aspects defined in heuristic 15.2 were developed in the e-learning software and configured in the supporting Learning Management System; specifically, this included support for levels, points, badges and a leaderboard.

The student response to levels was positive in terms of helping them to estimate their progress and in motivating them to get to the next level. The student response to points and badges in motivating them to work hard and progress was mixed, and remained unenthusiastic in the focus group:

"*Maybe since we're at an age that… maybe we won't care enough about virtual badges and awards and stuff, I think that's what he assumed. It won't actually increase motivation for many of us, but maybe for some of people it will work. Maybe if it was altered in some way it could increase motivation maybe increase competition between the class to better perform*." [Student 19]

One of the challenges is that the implementation of gamification elements is tied directly to the Learning Management Systems (LMS) which hosts the learning content. Support for gamification is not widespread or equal between LMS' and would therefore be impacted by a school's choice of LMS. In the context of Phase2-Cycle2, the LMS that was chosen was purported to offer native support for gamification elements but, unlike some other systems, it did not allow the ad-hoc definition of triggers for achievements. Instead, offered a limited set of award triggers based on completing a module, completing a module on time, completing a module early, and completing skills which were associated to a module, skills advancement which was further linked to advanced modules.

Overall, the level of granularity (module level) supported by the LMS was too coarse, and the triggers for the award of achievements were inappropriate, both pedagogically and in motivating the student participants. One student reported this, aptly:

"*The award of badges should be on an achievement. How they should work is that if you complete a quiz in a different way than the others, you get rewarded for something that others didn't do differently, or maybe badges for additional challenges that students can select*." [Student25]

The award of points become the basis of the leader board; again, the same challenge in configuring pedagogically appropriate triggers is apparent. Results from the survey instrument showed the overall student response to leaderboards is non-committal; in addition, the student response to leaderboards is non-committal in the scenario that they are a student doing well. However, a positive student survey response is received in the scenario that they are a student performing weakly. The discussion in the focus group did not lend much support to leaderboards.

"*It's like failing a test; it tells you to work harder for the next test. It is telling you to give more attention.*" [Student14]

"*There are some people who will be very disappointed that they are at the bottom so instead of trying harder they will try less*." [Student18]

"*Maybe you don't want other people to see your score, or you don't want to see other people's score so you don't get disappointed*." [Student19]

The findings in Phase2-Cycle2 do not offer supporting evidence towards heuristic 15.2; however, it is postulated that this was primarily due to limited LMS support relating to coarse granularity and inappropriate achievement triggers towards points, badges and the leader board. Heuristic 15.2 was therefore updated with further guidance notes for teachers and a warning that:

"*Extrinsic gamification elements are typically implemented within the Learning Management System (LMS); therefore, it is crucial that the school's LMS is evaluated to identify whether it supports the planned gamification strategy. If it does not support gamification, or offers limited support to key aspects of the gamification strategy, then consider not implementing gamification or implementing it in an unplugged manner, outside of the LMS*."

Other challenges and bugs within the LMS meant that for Phase 3, the study reverted back to the original SCORM LMS, and hence extrinsic gamification was not tested in Phase 3.

Several other heuristics were either not exemplified in the e-learning software or only partially evidenced. The e-learning software did not include the responsive design and consideration for the technical affordances of mobile devices; hence, it did not implement heuristic 11.1: Support collaborative and situated learning via mobile devices. In addition, although the e-learning software is strongly focused on active learning and contains numerous activities, the inclusion of true guided discovery and problem-based learning (PBL) within the timeframes offered by each study cycle, and the five hours of e-learning content, was not pedagogically feasible. Hence, heuristic 4: Use problem-based learning (PBL) to facilitate learning is not validated beyond the evaluation from education experts and teachers. Following on from this, it was identified in Phase2-Cycle1 that heuristic 6.2: Exemplify computational thinking in problem-solving activities did not have a significant coverage in the e-learning software; hence, it is only partially evidenced.

The most important area that is only partially evidenced and has received mixed (often negative) feedback is collaborative and social learning; this is covered in the following heuristics:

- 9: Use social-interaction to increase learning and promote higher-order thinking.
- 11: Use collaborative learning activities.

- 11.1: Support collaborative and situated learning via mobile devices.
- 12: Develop and nurture networks to support learning.

Collaborative activities were consistently ranked poorly in Phase 1 and 2, which was re-confirmed in Phase 3 with a larger student sample. Phase 1 and 2 student feedback on whether collaborative activities supported their understanding of the subject matter is mixed; although Phase 3 results on the same question offered a more positive median student response of **agree (4)**. The more concerning factor is that throughout the study, the students' engagement with collaborative activities is limited, and when engaged was often superficial. This is also clearly represented in Phase 3 with the larger student sample. The Phase 3 study did not provide deeper qualitative feedback in this respect, but these seemingly poor results are considered in light of the qualitative feedback in Phase 1 and 2. Open responses from the survey instruments and focus groups in Phase 1 and Phase2-Cycle1, show the students have a good conceptual understanding of the value and benefits of collaborative learning.

"*The collaborative activities helped me learn a lot as I heard about other people's opinions on the subject*." [Student 25]

"*The collaborative activities gave me and my partner the opportunity to help each other understand the questions we had. One could answer the questions of the other, which was really helpful in order to complete our task*." [Student 14]

"*The collaborative activities gave me motivation to work harder in order to not fall behind my partner*." [Student 18]

"*Encouraged me to better understand the material rather than simply glossing over me, because I had to explain it to my partner*." [Student 13]

The students acknowledged that collaborative learning is equally useful in class, but technology-enhanced collaborative activities are artificial in a classroom context and much more suited for homework, where you are not co-located with your fellow students. This was also commented by Teacher 1 in the pilot phase of the study. In the context of this study, the majority of time spent using the e-learning software and CLE was in class and so it did not feel natural to the students. The reality is that an optional research study is not a suitably attractive proposition for students to spend their free time on, much less to coordinate with others to jointly spend their free time on. However, the consensus from both Phase2-Cycle1 focus groups was that if collaborative learning and a collaborative learning environment were integrated into the normal learning process (including homework) that spans the academic year, then they would have really liked to have done it.

"*yes it's much better than what we currently have to submit work from home*." [Student 14]

What was tentatively postulated in Phase 1 was more clearly established in Phase2-Cycle1: an experiment design to give feedback on collaborative learning would need to more naturally reflect the learning process across a longer duration in which the students have weeks/months to review, respond and interact. In this study, this was not possible; even in Phase 3, the student engagement was approximately two weeks, of which most time was spent in class. What is clear and hence reflected in the pedagogy, is that collaborative and social learning require a long-term investment to prepare students, and to build a culture and learning community to support it. This is reflected in heuristics 11, 12 and Vol 2 Appendix E section B.6.

Whilst the findings from student usage of the e-learning software does not offer positive evidence of the aforementioned heuristics, the adverse, and overall mixed, findings are not so strong as to discredit collaborative and social learning, and hence the heuristics are not removed from the pedagogy.

7.8 Phase 3 Learning Performance

As discussed previously, Level-1 and Level-2 of the e-learning software provide foundational concepts on algorithms and computational thinking, whereas Level-3 and Level-4 provide learning material on flowcharts and pseudocode of direct relevance to the pre- post-test exam. The duration of the student engagement with the e-learning software is therefore reported for all four levels (L1L2L3L4) combined, and separately for Level-3 and 4 (L3L4) combined. The learning performance discussed in this section is based on a student engagement with all four levels with median 196.5 minutes (95% central range 172 minutes to 219 minutes), and with Level-3 and 4 combined with median 64.5 minutes (95% central range 56 minutes to 100 minutes). The aforementioned durations do not include time spent on the collaborative learning environment working on collaborative or individual assignments. As reported in section 6.6.7.3, based on student submissions, the level of student engagement with the CLE was perceived to be nominal, but the duration of that engagement cannot be estimated. Of importance is that none of the students submitted the four assignment activities in Level-3 and -4; these would have given students an opportunity to practice skills directly transferable to the post-test. It is therefore postulated that the lack of engagement with these assignment activities had an adverse effect on post-test results. Although, the scale and significance of that effect cannot be estimated based on current data.

Interesting correlations were identified between the teachers' Key Stage 4 predictions (KS4Prediction) for students and the time they devoted to the e-learning software. A statistically significant medium effect negative correlation was identified between KS4Prediction and Level-1 learning time. Causality is theorised that students with a higher KS4 prediction require less time to understand the foundational material covered in Level-1; hence, they spend less time on the level. Conversely, statistically significant medium effect correlations were identified between KS4Prediction and Level-4 time and Level-3 and -4 combined time. Causality is theorised that students with a higher KS4 prediction are more driven to do well in the later more challenging levels, and therefore are willing to spend more time on them. However, it should be noted that a correlation was not identified between KS4Prediction and learning performance, as defined in %Post-Test or %Change.

After their engagement with the four levels of the e-learning prototype, the students did not express confidence that they could pass a test on the subject matter. The median student response was **neither agree nor disagree (3)** with the statement *"After completing the 4 levels of the e-learning software, I was confident that I would be able to pass a test on it."* However, this lack of confidence (Question 6N) and the students' perception of their own learning (Question 12 C) did not offer a statistically significant correlation with learning performance metrics of %Post-Test and %Change.

Considering %Post-Test was assessed by the Kolmogorov-Smirnov test to have a non-normal distribution, it was decided to analyse pre- post-test learning performance using parametric tests (Paired Sample T-Test), bootstrapping and non-parametric tests (Wilcoxon Signed-Ranks Test). All three tests, with and without outliers reflected a statistically significant improvement in learning performance. The learning performance improvement between pre-test and post-test had a mean of 19.22% points (95% CI 15.68% to 22.76%). The learning performance improvement of %Change had a median of 20.97% points (95% central range 12.90% to 25.81%). We therefore conclude that based on the level of engagement previously outlined and the limitations therein, a statistically significant learning performance improvement can be generalised to the GCSE student population from usage of e-learning software designed in adherence to the e-learning pedagogy.

This is further supported by the correlation analysis which shows a statistically significant medium effect correlation between the time students spent using the Level-2 software and %Post-Test results. Furthermore, there is a Tier-2 small effect correlation between the time students spent using all levels of the e-learning software and %Post-Test results. Causality is theorised that the more time students devoted to using the e-learning software, the better their post-test learning performance was.

Considering the post-test was created using exam questions from EDEXCEL, OCR and AQA examination boards, it is possible to theorise the examination results possible within the GCSE student population. It should be noted that there are limitations within this analysis since the first examinations were in 2018, so grade boundaries for the new specification had not been released at the time of this study. With reference to recent GCSE Computer Science grade boundaries from EDEXCEL (Pearson 2016), OCR (2017) and AQA (2016), a realistic theoretical model of the grade boundaries for the new GCSE specification was developed. Within this theoretical model, a Grade F (Low Grade 2), is approximately 16.33% and a Grade C (Grade 4 – Standard Pass), is approximately 37.35%.

Using parametric tests (One-Sample T-Test) with and without outliers and with bootstrapping, all indicate that we cannot reject the null hypothesis that the %Pre-Test mean is equal to the hypothesised Grade F target value.

Although, %Post-Test is not normally distributed, there is no equivalent non-parametric test. Using parametric tests (One-Sample T-Test) with and without outliers and with bootstrapping, all indicate that we cannot reject the null hypothesis that the %Post-Test mean is equal to the hypothesised Grade C target value.

We therefore conclude that, based on the level of engagement previously outlined and the limitations therein, the GCSE student population can move from a hypothesised Grade F target value to a hypothesised Grade C target value following usage of the e-learning software designed in adherence to the e-learning pedagogy.

7.9 E-learning Evaluation Protocol

As discussed in section 2.3.3, there is a research deficit for e-learning evaluation protocols that focus on pedagogy. Additionally, the need for a rigorously defined e-learning evaluation protocol is established by several recent national evaluations and the inherent limitations of those evaluations. This study proposes a rigorously defined evaluation protocol based on evaluation best practice, but which is unique in its explicit consideration of the educational setting for software usage, its detailed evaluation criteria, its focus on both pedagogical and content quality (learning objectives), and its provision of quantitative and comparable results.

The e-learning evaluation protocol had matured to the point where Phase 3 feedback from education experts and teachers was minimal, and the proposed refinements have been implemented in the final version of the protocol.

The teacher feedback indicated their school's limited experience, limited use of e-learning software and a lack of school-wide policy. Furthermore, the majority of teachers report limited or no personal experience of integrating e-learning software into their teaching. Whilst current usage of e-learning software is limited, the teachers showed a clear understanding of the benefits of e-learning software and expressed that it could have positive educational and motivational impact towards computing.

Although the teachers had limited or no experience in selecting or evaluating e-learning software, they expressed that if they were called upon by their schools, they would get involved in an e-learning evaluation and, most importantly, that they could use the heuristics and the evaluation procedure described in the workshop to evaluate e-learning software.

Despite the teachers' positive feedback towards the e-learning evaluation protocol and their limited recommendations for improvement, there remains an implied concern that the e-learning evaluation process may be too time consuming for teachers to fit into their busy schedule. This was not reported by teachers, but was a concern raised by one education expert; this could, in the future, be validated by further empirical evidence of teacher usage. Acting on this concern, in Phase 3 a timeline analysis was carried out to analyse each of the tasks in an e-learning evaluation to identify any scope for further efficiency, and to estimate a best and worst-case duration for each activity. The best and worst-case evaluation scenarios considered:

1. The timeline analysis reported in Vol 2 Appendix C.4,
2. E-learning software of 1-hour typical learning duration and 6 Learning Objectives, and
3. Evaluators who are double experts,
    a. The worst-case scenario additionally considers the evaluators to have zero or minimal experience with the heuristics and evaluation protocol,
    b. The best-case scenario considers the evaluators experienced with the heuristics and evaluation protocol.

The worst-case scenario estimates approximately 14 hours from the facilitator and 9 hours 30 minutes from each evaluator. The best-case scenario estimates approximately 6 hours 15 minutes from the facilitator and 5 hours 45 minutes from each evaluator. It follows that the best-case scenario can be accommodated within one day, whereas the worst-case scenario is better planned across multiple days.

This study provides findings that partially validate the accuracy of the heuristic evaluation. Both teacher groups provided feedback that was accurate in relation to the known characteristics of the e-learning software under evaluation. As per the intended purpose, the e-learning evaluations and in particular the debrief sessions added great value in identifying specific pedagogical shortcomings and recommendations to improve the software. Validity and reliability are further supported by the comparison of Group-1 and Group-2 heuristic evaluation results, which show a notable similarity on the Pedagogical Quality results of 59% and 56%. As detailed in Vol 2 Appendix C.6.1.1, a more in-depth review of the Group-2 responses also demonstrated the potential for even closer alignment.

In contrast, a similar comparative analysis of the Group-1 and Group-2 evaluation results for the six learning objectives throws concern on the reliability and validity of the evaluation protocol; there is a significant discrepancy on the Content Quality results of 88% and 27%.

A deeper analysis offers a partial explanation of this discrepancy. Group-2 responded that for three of the six learning objectives, they felt that the e-learning software slightly counteracted the successful learning of the learning objectives. A negative value for support of learning objectives is typically reserved for e-learning software, whose learning content is factually incorrect or inaccurate in terms of a given syllabus, or that in some manner explicitly obstructs the learning of the learning objective. It is doubtful that the learning content was inaccurate or poorly designed to the extent that it would obstruct learning on these topics. This assertion is made because the learning content was synthesised from official material from the three main examination boards, and practice questions and activities were sourced and adapted from past examination papers and education experts from the Computing at Schools Network. Furthermore, with reference to Figure 75, it is evident that for learning objectives 1, 2 and 6; the responses from individual evaluators, and the mean, mode and median values, are all radically different to the debrief responses.

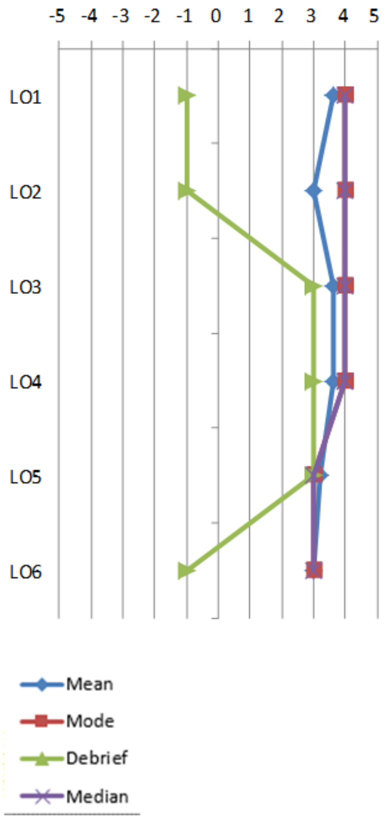


Figure 75: Phase 3 - Group-2 evaluation of support for learning objectives

This is further supported by a correlation analysis; both groups demonstrate the trend that the mean, mode and median typically offer a strong correlation with the group's final debrief response. The most notable exception to this is the Group-2 - Learning Objective Support correlation, which shows that the correlations are not statistically significant, the lowest mean to debrief correlation, and zero correlation between mode and debrief, and median and debrief. The previous analyses indicate that the debrief responses for learning objectives 1, 2 and 6 do not reflect normal evaluator behaviour, and are atypical. An investigation of the audio transcripts from the debrief session offers a partial explanation; Group-2 had a significant challenge in aligning on the given education setting (refer to Vol 2 Appendix C.6.1.2). A significant portion of their debrief discussion reflected an incorrect perception that the Level-3 software should include pseudocode, and that the coverage of data types, and variables and constants should be at a level to prepare students for coding (programming). This incorrect perception would explain a low response for the level of support for learning objectives 1 and 2, but would not explain the group's assertion that the software counteracted the learning of these areas. Furthermore, it does not explain that for software dedicated to the instruction of flowcharts, that Group-2 responded that it counteracts the learning of flowcharts in the context of inputs, processing and outputs (LO6).

These findings identify two critical areas in an e-learning evaluation:

1. The importance of the facilitator's role within the evaluation, and
2. Alignment with the educational setting prescribed for the evaluation.

The primary purpose of the debrief session is to aggregate findings and build consensus, it is therefore the primary objective of the facilitator to promote and enable this. In addition, the facilitator in a debrief session goes beyond being an enabler and the gatekeeper of group-process; the facilitator must be a content expert (knowledgeable of the syllabus, the heuristics, and the e-learning software) and therefore able and active in correcting misconceptions. The debrief session offers a final opportunity to correct mistakes by the evaluators or any misconceptions they may have, before they influence the final group response.

In both groups, there were instances were individual evaluators had missed particular functionality in the e–learning software and therefore responded that particular heuristics were weakly or not supported. Such misconceptions are often corrected by other evaluators in the group, but if not, then they must be corrected by the facilitator to avoid corrupting the group result.

Ensuring the group's evaluation is aligned with the education setting is crucial; this was a challenge in Group-2 and to a smaller extent in Group-1. If a group is evaluating based on a misconception of the learning context then they will evaluate unduly harshly or leniently; therefore, the facilitator must step in to realign the group's understanding of the education setting. This is to ensure the evaluation is based on an agreed, realistic and documented educational setting. This in turn affects reliability since other groups doing a similar evaluation should evaluate based on the same education setting. In addition, it is also recommended to increase the emphasis of the education setting presentation (before the evaluation) and also include a short reminder presentation at the start of the debrief session.

On multiple occasions evaluators commented that their individual response was a mistake because they had misunderstood the heuristic (and its criteria). This is often self-correcting since it comes out in discussion with the group. Much rarer will a significant portion of the group be evaluating under a mistaken understanding of the heuristic. To pre-empt this, it is important that the evaluators have access to the evaluation criteria as they discuss a heuristic. Also, that the facilitator is able to give clarification of a heuristic and its criteria, and that a facilitator actively engages if the evaluators are not evaluating a heuristic according to the stated criteria.

The above scenarios are particularly damaging when there are dominant figures within the evaluation group. It is already a part of the facilitators role to balance such dominant figures, but it becomes critical if a dominant evaluator is working under a misconception and driving the group in the wrong direction.

It is unrealistic to expect that each evaluation will have a professional or highly experienced facilitator engaged; nevertheless, it is important that this role is actively assigned within the evaluation debrief session. More importantly, that the person taking on the facilitation role is a dual expert with comprehensive knowledge of the education setting, and additional experience of both the heuristics and the e-learning software. To support this, additional facilitator guidelines are provided in the evaluation protocol under Vol 3 Appendix N section A.

8 CONCLUSION, CONTRIBUTION AND FUTURE WORK

To support the UK's high-school teaching community (and other countries undergoing a curriculum transition to a more computer science focus) this study proposes that quality e-learning software tailored to the computing curriculum can be a beneficial to the teaching community. It considers that pedagogy is one of the most critical factors in successful e-learning and that concerns still persist over the quality of e-learning software. In response, this research has developed an e-learning pedagogy and associated evaluation protocol to ensure the pedagogical quality of computing e-learning software used in schools.

The proposed e-learning pedagogy is comprehensive in nature, and has received input and review through multiple iterations from education experts and teachers. It has reached the point where it is assessed to be: appropriate for computer science education; appropriate for 15 to 18-year olds (Key Stage 4 and 5); offers balanced and comprehensive pedagogical coverage; and can feasibly be implemented within a high-school environment.

It is, though, acknowledged that the scale of the pedagogy and the endeavour needed to fully utilise it still leaves some residual concern, with one education expert questioning how and whether it will be practically used by teachers. The heuristics in themselves can feasibly be implemented in schools and where heuristics have possible implementation challenges, they are documented for appropriate curative action. However, the overriding conclusion is that when designing e-learning software or evaluating software for use in schools, the heuristics that will be applied must consider the reality of the school context in which the e-learning software will be used.

Moving beyond a theoretical synthesis and review, the pedagogy was developed with input from a practice-based implementation of e-learning software which received feedback from GCSE students. This feedback gave input in refining some of the heuristics, demonstrated the viability of developing e-learning software based on the pedagogy, and most importantly reflected positive support for the majority of the heuristics. It is, though, acknowledged that within the limitations of this study, several heuristics were not practically evidenced via student usage of the prototype e-learning software; the most notable pedagogical areas were problem-based learning, and collaborative and social learning.

Finally, Phase 3 generalised statistically significant results showing that usage of the e-learning software can lead to a mean 19%-point increase between pre- and post-tests. This in turn is theorised to be the equivalent of a GCSE Computing student moving from an F to a C grade through the use of only the e-learning software. In this respect, we can reject the null hypothesis (H_0) in favour of the hypothesis:

- H_1: The use of e-learning software designed in adherence to the pedagogical heuristics presents improved student learning performance.

Phase 3 also identified notable correlations between motivation and student time spent using the software, and between time spent using the e-learning software and improved learning performance. The direction of causality is difficult to attribute between time spent and motivation. However, causality is apparent, increased time spent using the software leads to improved learning performance.

Similar to the e-learning pedagogy, the e-learning evaluation protocol received input and review through multiple iterations from education experts, and practice-based feedback from two groups of teachers during the Phase 3 workshop. The evaluation protocol has matured to the point where feedback from education experts and teachers was minimal, and had already been implemented in the final version of the protocol. The teachers expressed the learning and motivational benefits of e-learning software as a teaching resource, and the opinion that they could use the heuristics and the evaluation protocol to evaluate e-learning software for school use.

Although not reported by the teachers, there remains an implied concern that the e-learning evaluation process may require time not easily available in their busy schedule; this can be validated by further empirical evidence of teacher usage.

This study provides findings that offer preliminary validation of the accuracy of the heuristic evaluation in terms of: feedback that was accurate in relation to the known characteristics of the e-learning software; valuable feedback in identifying specific pedagogical shortcomings and recommendations to improve the software; and the validity and reliability of the inter-group comparison of pedagogical quality. However, a similar inter-group comparison of content quality showed a sizeable discrepancy in evaluation results. A hypothesised explanation for this desynchronization has been provided, and mitigating guidelines added to the evaluation protocol; nevertheless, it throws some concern on the reliability and validity of the evaluation protocol, which can only be fully dispelled by a follow-on study.

8.1 Research Contribution

Considering the Royal Society's recent report (2017b), the three critical factors that prompted this research (shortage of qualified specialist teachers, lack of subject specific pedagogy, and inadequate technical teaching resources), have further intensified in the UK. This research addresses these factors by supporting the increased use of e-learning software in high-school computer science, whilst simultaneously safeguarding the pedagogical quality of the software.

Specifically, the research aims were fulfilled by the provision of an:

1. e-learning pedagogy that focuses on high-school computer science (as of January 2018, an equivalent holistic set of heuristics could not be identified); and
2. an e-learning evaluation protocol for the evaluation and selection of e-learning software for use high-school teaching (again the characteristics of the protocol, make it arguably unique).

Although the pedagogy and associated evaluation protocol were well received by the teachers involved in this research, their practical contribution remains unproven since that is contingent on their significant uptake by the high-school teaching community.

What is clear though, is that this research contributes to a severely under-researched area, in terms of high-school computing pedagogy, and specifically e-learning pedagogy. Furthermore, this study's contribution is executed with a high degree of research rigour and generalisable findings, which has been reported as typically lacking in educational research.

Whilst there are a variety of texts on e-learning instructional design; this research differs by providing an accessible set of heuristics for e-learning pedagogy that provides the essence of e-learning pedagogy to the teacher audience. This research focus contrasts with previous research on e-learning heuristics, which focused almost entirely on usability with little reflection of the complexities of the learning process. Furthermore, whilst numerous researchers expound the need to assess the educational quality of e-learning software, few have proposed a tangible and detailed focus on the evaluation of e-learning pedagogy and content quality. Hence, this study also redresses that gap.

Whilst this study takes the UK as its backdrop, a significant number of developed countries are undertaking similar initiatives to give an increased focus to computer science in their high-school curriculums. Those in the earlier stages of these initiative have a common thread of challenges in transitioning teachers to a new curriculum, ensuring teachers have both subject and pedagogical knowledge to support their teaching, and the relevant teaching resources to support student instruction. These factors thereby make this research broadly transferable to those countries.

8.2 Future Work for the E-learning Pedagogy

It is reaffirmed that the aim of this research is not to propose e-learning as a replacement for high-school teachers, but as a support and as a tool for teacher use. Hence by design, this study does not consider a control group by which students are taught by traditional didactic methods vs e-learning software designed in adherence with the pedagogy.

Despite the significant work and findings of this research, it is considered a mature beginning, primarily focused on the development of the pedagogy, its associated evaluation protocol, and the effect on student learning and motivation. There remain several possibilities to further empirically establish this research or develop it further into new research avenues.

An initial step in further establishing the e-learning pedagogy is to build an empirical body of evidence of multiple e-learning software whose design is guided by the pedagogy. In this manner, further refining the pedagogy, based on practice-based evidence in schools.

Building on the proposed body of empirical evidence would be a correlation between the e-learning evaluation score and learning performance. In this manner establishing that increases in the *"Educational Value"* (as defined in section 5.4.3) of the e-learning software correlates to an improvement in student learning performance. As discussed in the next section (8.3), this could potentially lead to comparative evaluations of several purportedly equivalent e-learning software, some designed in adherence to the pedagogy and some without pedagogical design guidance. This would establish findings on whether the evaluated *"Educational Value"* of an e-learning software is impacted by adherence to the pedagogy and whether there is a statistically significant correlation with learning performance.

As acknowledged in this study, certain pedagogical areas were weaker evidenced in the practice-based intervention. Longitudinal studies can be carried out that give specific focus to these pedagogical areas and provide more conclusive school-based evidence of their potential benefits.

The pedagogy's hypothetical transferability can be established using the pedagogy in the design, or the evaluation of e-learning software from other national curriculums, or in other STEM subjects.

8.3 Future Work for the E-learning Evaluation Protocol

As discussed in section 5.4.9, a standard approach to ascertain the performance and validity of an evaluation protocol is to conduct a comparative evaluation of the same software using an established evaluation protocol with the new protocol. This would be an important area of investigation. However, based on the existing literature review, there does not seem to be an equivalent established protocol, which suggests a positive indication of the uniqueness of this e-learning evaluation protocol. Nevertheless, the preliminary findings from this study suggest that additional studies are needed to further establish the reliability and validity of the evaluation protocol; follow-on studies can use multiple evaluation groups to evaluate the same software and correlate their findings.

An interesting area of further investigation would be to use the evaluation protocol for a comparative evaluation of several purportedly equivalent e-learning software. This would help establish whether the protocol offers practical value in the selection of e-learning software.

Another interesting and potentially valuable follow-on study would be to correlate the findings of the e-learning evaluation against an evaluation based on Kirkpatrick's (1967) training evaluation model. This research already goes some way in comparing the e-learning evaluation findings against Kirkpatrick's 1st and 2nd steps: reaction and learning. A long-term study could be devised to establish whether the e-learning evaluation protocol offers any indicators towards Kirkpatrick's 3rd and 4th steps: changes in behaviour and results.

With long term use of the evaluation protocol, empirical evidence can be used to define reference values for each of the heuristics and for overall educational value. This would enhance the evaluation protocol by setting reference thresholds for good, moderate and poor e-learning software; this has previously been explored (at a cursory level) by Abderrahim et al. (2013).

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