Blending technological, cognitive and social enablers to develop an immersive virtual learning environment for construction engineering education

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Blending technological, cognitive and social enablers to develop an immersive virtual learning environment for construction engineering education

Proefschrift

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aan de Technische Universiteit Delft,
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voorzitter van het College voor Promoties,
in het openbaar te verdedigen op 10th January 2017

door

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AEC	Architecture, Engineering and Construction
VRE	Virtual Reality Environments
VR	Virtual Environment
AR	Augmented Environment
CEE	Construction Engineering Education
BIM	Building Information Modelling
CGS	Computer Generated Simulation
SDK	Software Development Kit
CSCW	Computer Supported Cooperative Work
WBS-LS	Web-Based Simulated Learning System
RID	Research in Design
DIR	Design Inclusive Research
ODR	Operative Design Research
RC	Research Cycle
LO	Learning Objects
HCI	Human Computer Interface
TPACK	Technological Pedagogical Content Knowledge
LMS	Learning Management System
MOOC	Massive Open-Source Online Course
F2F	Face to Face
LOR	Learning Object Repositories
OU	Open University
OpenGL	Open Graphics Library
API	Applications Programming Interface
GPU	Graphics Processing Unit
PLE	Personal Learning Environment
FFM	Five Factor Model
SQL	Structured Query Language
RDMS	Relational Database Management System
CAD	Computer Aided Design
PUC	Pervasive Ubiquitous Computing
ADPCM	Adaptive Differential Pulse-Code Modulation
RPC	Remote Procedural Call

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Chapter 1

The addressed research domain and objectives

1.1. Introduction

Overall, this research contributes theoretically to the debate about how technology utilisation leads to progressive education. However, the origin of the completed inquiry and developmental investigations is in the need to keep dislocated construction engineering students engaged in procedural activities normally conducted onsite by co-located peers.

1.1.1. Current trends influencing construction engineering education

By now, virtual construction has been widely accepted in the architecture, engineering and construction (AEC) industry [1]. The software technological enablers have been adapted to the need of virtual construction. They provide a visual coordination of the construction processes and enable all AEC stakeholders involved in a given real world project to identify potential conflicts (clashes) well before any site works are commencing [2]. Simulated virtual environments enable the application of cognitive knowledge and practice of psychomotor skills in an interactive virtual world [3]. Computer technology using multiple software platforms to simulate real life scenarios has brought about advances in visualisation of virtual reality environments (VRE) and has enhanced the users' experience [4]. The video games industry has embraced multiple software platforms to simulate real life scenarios and to facilitate high level interactivity through virtual social encounters. Notwithstanding, for the time being, just a relatively small minority of construction engineering educational professionals are using the currently available technological enablers as a means to disseminate knowledge. The idea that learners may take control and may manage the educational resources (enablers) far better than they enhance most of the educators nervous, but for those pursuing new approaches and successes in AEC education it brings some exciting challenges [5].

As technological enablers, virtual reality (VR) and augmented reality (AR) provide a connection between the theories and the practice on site. They are used in the design, development and implementation practice for practical reasons, such as: (i) to improve collaboration, (ii) to co-ordinate and plan future activities, (iii) to reduce lead time, and (iv) to speed up information flow on live construction projects [6]. Because these technological enablers provide visualisation prior to the commencement of the on-site work, stakeholders have an opportunity to spot potential mistakes and/or flaws, and make changes to the design at minimum costs and without safety violations [7]. As a result of advances in mobile technology and ubiquitous network connectivity, the construction process has become more informed (sometimes even said, more intelligent) [8]. Integration of enabling technologies into the design and build phase of a project has had an influence on how AEC conduct business. The main drivers for adaptation of these technological enablers are (i) the need for sustainable construction technics, (ii) consideration of government regulations, (iii) competition to provide efficient and quality products and services, (iv) requirements for a knowledge economy, and (v) energy conscious end-users/stakeholders [8].

Construction project completion depends on both the physical and the social sharing of problem solving activities. The sort of problem solving carried out simultaneously within the AEC environment is very distinct. Scribner (cited in Brown) records how complex mathematical calculations can be solved by practitioners using their environment directly [10]. Spatialisation of knowledge, including the use of social media such as Facebook, Twitter, YouTube and online forums, has changed the current generation of human aspirations, expectations, perceptions and how they socially interact [11] [12]. Enablers (social and technological) provide the foundations where upon knowledge is assumed as meaning and understanding and is constructed through social means but accessed through technological means [13].

1.1.2. Challenges raised by the current pedagogical, social and technological developments

Learners who sign up for a study programme that applies traditional means of content delivery are being increasingly exposed to the proliferation of non-traditional teaching methods. The use of collaborative online environments has become the way in which knowledge is shared and accessed and has given rise to a number of virtual groups becoming learning communities [14]. Technology-enabled education often involves co-located learning on campus as well as dis-located learning off campus [9]. Established evidence-based theories of learning are now recognised as central to the development of learning practice across all fields of learning activity [10]. The result of a person's learning experience can determine improved performance and measure the potential for future learning success.

Augmented and virtual reality technologies are widely used in the current daily practice of professional education on multiple levels. For AR/VR to be successful, the created environment must deliver the feeling of presence. Success depends on the extent of keeping the participants immersed in the activities. Tricking the brain into thinking in real world in AR/VR environment is difficult even with high end hardware such as CAVE and head mounted technology. The recent literature tends to concentrate on the technical approach to AR/VR learning environments. Nevertheless it suggests that consideration must be given to the design fundamentals of presence in a virtual world rather than approach the development as a means of simulating existing experience. It needs to be approached as a means in its own right if one is to create new forms of stimulation experience [15]. Learning from how television programmes evolved from a medium that brought theatre into the home to the current offerings, AR/VR development must be built as something unique and not yet experienced if we are to create an end user response in a way that indicates their perception of the events are real [16].

Human diversity is a central consideration, which must be applied to all forms of AR/VR environments and must be accounted for at developing Web3D learning tools. The success of applying Web3D technological enablers to disseminate construction engineering knowledge and to provide efficiency in construction engineering education (CEE) is dependent on: (i) the human user (actors) at the core, (ii) the application challenges in CEE and (iii) the sophistication of the technologies. The level of acceptance of a blended multi enabler implementation is in correlation with how the delivery framework supports the illusion of human senses when interacting in Web3D [17]. The current systems are merely mechanisms to deliver and to transfer knowledge. The (human) user and the nature of social behaviour are in connexion with each other and it is human repetitiveness on an individual basis that defines the Web3D social behaviour structure [18]. Equally, it is this relationship that allows for the modifications of social norms. For example, Web3D learners can choose to ignore, replace or reproduce social structures such as traditional teaching methods or codes of etiquette [11]. Human diversity poses an added challenge for AR/VR system developers in terms of designing an effective virtual environment. But in the end, obviously the users' capabilities and their limitations are that eventually determine the effectiveness of the design [19].

1.1.3. Opportunities of cognitive stimulation in construction engineering education

Web3D online games have successfully blended technological and social enablers to produce a highly popular social outlet for digital savvy users. There are also numerous examples of when AR/VR game technology blended with game theory has been applied to develop virtual learning environments, mostly at the expense of learning concepts [20]. In order to achieve better results, this research considers how advanced technological enablers can be blended with cognitive and social enablers. Research to date illustrates that AR/VR games are largely underpinned by learning and gaming theory and focus on a game plan based on right or wrong answers [21]. In order for an AR/VR technological enabler to be used successfully as a web-based learning and teaching tool, consideration must be given to a cognitive and social enabler framework in the context of a web-based stimulating learning system [21]. It is common for digital savvy learners to spend their days on: (i) social networking web sites, (ii) emailing, (iii) surfing the internet and (iv) instant messaging[1,] thereby suggesting that Web3D technological enablers when blended with cognitive and social enablers can offer different spatialisation of knowledge, where knowledge is linked despite being in multiple locations, reconstituted and contested across time and space [21].

The influence of technology on increasing cognitive stimulation and perceptive immersive learning requires further inquiry. These promising technologies still need further research experiments, investigation and analysis because of their complexity. Web3D has meant that learners are more autonomous and educators must re-think on how to motivate and engage them [22]. Learning is the continued changing process influenced by psychological and social factors [26]. A key driver for learning is to help people become more employable and or productive in the work place. CEE utilise pedagogical bridges such as work placement to integrate undergraduate learners from college to work [23]. As a cognitive enabler, work

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[1] Harris Interactive. 2006. College students surf back to campus on a wave of digital connections. http://www.harrisinteractive.com/news/newsletters/clientnews/2006_alloy2.pdf. [Accessed October 2016].

placement stimulates a number of real time scenarios which requires analysis, evaluation, reflection and resolution decision making [24]. Technological advancements in AR/VR and multimodal user interaction offer new ways to stimulate CEE work placement pedagogy [25]. Today we can draw on the experience of numerous applications where AR/VR technological enablers are applied to invoke or increase cognitive stimulation. Examples can be found in areas such as (i) AEC design and build, (ii) engineering maintenance training, (iii) physics and (iv) applied social psychology [25].

1.2. Research domain and problem

This research indirectly contributes to the ongoing knowledge exploration about traditional versus progressive education [26]. How to design and deliver progressive education is exercising the minds of educationalists, students, parents and policy makers. The motivation is twofold, (i) the generation divide, and (ii) the need for improved performance of mankind. This research directly contributes to the knowledge gap on how the blending and application of technological, cognitive and social enablers and current student interactions with same leads to progressive web-based education. The origins of this investigation stems from the need to keep dislocated construction engineering students engaged in procedural tasks normally carried out in class by their co-located peers.

1.2.1. On the multidisciplinary nature of the research domain

The evidence from our research to date indicates that there is a knowledge gap between educators who think of and use technological, cognitive and social enablers as individual tools and learners who intuitively use blended enablers as a foundation base for everything they do. There is also growing research evidence demonstrating that, with the advancement of visualisation and AR/VR technologies, comes the provision for cognitive stimulated learning to enhance the learner's experience [6]. Technological enablers such as virtual construction software systems provides "a connection between theory and practice on site" and is used as a practical tool on construction sites to (i) improve collaboration, (ii) co-ordinate and plan future activities, (iii) reduce lead time and (iv) speed up information flow. As briefly noted earlier, virtual construction of a project provides a greater understanding of the multidisciplinary design decisions and how these affect each other. The changes in how the AEC industry conduct business have come about as a result of (i) the need for sustainable construction technics, (ii) governmental regulations, (iii) competition to provide efficient and quality products and services, (iv) requirements for a knowledge economy and (v) energy conscious end-users/stakeholders [27].

Many different technological enablers and implementations exists and range from entry-level desktop tools and applications to immersive portable means to high-end immersive, multi-media, computer-aided virtual environments (CAVEs) [28]. Head-mounted displays (HMD) have become the most commonly used device to provide visual interface. In large-scale industrial and academic applications CAVEs are used in which images are projected onto the walls, the ceiling and the floor using various projector devices [28]. The immersive simulation is based on the visual degrees of vision provided to the viewer. Among its uncountable practical applications, educational utilisation has remained somewhat limited. Regardless of the technological enabler used, immersive or non-immersive, the AEC industry practicing professionals are currently using technological enablers such as Building Information

Modelling (BIM), 3D graphics, head mounted visuals, sound and self-movement technologies to enhance the illusions for virtual construction activities.

As a direct result of proliferation of these technologies, researchers and computer scientists can now mirror practices happening in both the social and professional real world and disseminate them through Web3D platforms. Technology supported research is a rapidly growing area in education. One specific area of technology supported research has been devoted to examining (i) whether, (ii) how, and (iii) what, students learn from social media and video games. Video games offer technology supported setups to produce virtual simulated environments that enable the application of cognitive knowledge and practice of psychomotor skills. The overarching evidence indicates that both the AEC industry and construction engineering education (CEE) are experimenting with a wide range of technologically supported enablers. There is further evidence on the effects advanced computers systems have when applied to either CEE or the AEC industry practice. Initial surface findings have concluded that research into what are the optimal computer support systems for CEE is lacking and warrants some focused investigation.

1.2.2. Specific research problems addressed

There are numerous examples of AR/VR systems being applied to support all phases of construction cycles. Examples include (i) operator training for construction plant and machinery [29], (ii) automated progress monitoring, data collection, processing and communication between construction phases [30] and (iii) conceptualisation to integrate AR/VR technological enablers with building information modelling (BIM) systems that detect defects prior to commencement of construction [31]. Due to an increase in popularity and capability of technological enablers such as cloud computing and ubiquitous web-based AR/VR systems, the last few years has seen a marked increase in the exploration and development of AR/VR tools to enhance and enrich the construction processes and procedures [32]. The current literature highlights the emerging trends of: (i) computer generated multi-dimensional representations of an object or an environment displayed on a screen enabling user interaction [33], (ii) networked connectivity enablers, (iii) immersive multi-task problem solving systems, (iv) cognitive stimulation enablers (v) social gaming AR/VR environments, (vi) collaborative online enablers [34] and (vii) human factors and diversity issues. Together these trends have resulted in directing the scientific focus to progress from describing how AR/VR and other computer generated assistive technological enablers can benefit CEE, to describing how these actual systems are developed and applied [35]. Research has identified the benefits such technological applications bring to both CEE and the AEC industry, such as, virtual site tours for learners, virtual construction to mirror as-built planned projects for practitioners, clash detection to pre-determine contractual disputes and over all inter disciplinary collaboration enhancement [36].

Learning theories developed in the domain of social research have become widely recognised and accepted as relevant for the development of pedagogical support when using technological enablers to disseminate knowledge. Such enablers have strongly influenced how learners approach learning. For example today's learner is more likely to search online before ever resorting to a recommended text book and therefore is approaching learning using technological enablers from the onset. They have equally had a direct influence on the frequency of attendance to traditionally delivered lectures. When they are physically in attendance many use their technological enabled devices for social interaction and not for capturing the new knowledge being presented. It is now accepted that today's learner spends more time completing online or technology based tasks than he/she will spend reading a book. Therefore the question must arise around how one should use technology in order to contribute to learning in a meaningful way. Figure 1.1 is a summary of the trends that are having or have had a direct influence on dissemination of knowledge and provides focus on the specific knowledge domain of this research.

1.2.3. Considering the impacts of technologies

Computer technology in the form of computer generated simulation (CGS) is increasingly using video game software development kits (SDK) to simulate real life scenarios. The high level of interactivity is promoted both through social and work based virtual encounters. The use of these technological enablers for the purpose of knowledge dissemination is prevalent in the medical, business and military sectors. One assumed advantage of learning in an interactive simulated virtual environment is the potential it has to expose participants to high risk processes, maintaining visual and audible simulation and eliminating personal risk. The literature confirms that development of virtual environments enhances traditional training methods and learner experience [37]. Realistic and relevant virtual simulation requires careful consideration of numerous and complex behaviours that exist in the real world [38]. There are numerous examples where computer engineering researchers have developed intelligent virtual reality environments that animate AEC operations and processes [39].

The influence of immersive multi-task problem solving systems extends from visual and audio technologies through tactile, haptic and limbic technologies to brain, cognitive and VR technologies [40]. The generic term Web3D is commonly used to refer to any web-based three dimensional (3D) graphics technology [41]. In the CEE domain there are numerous examples

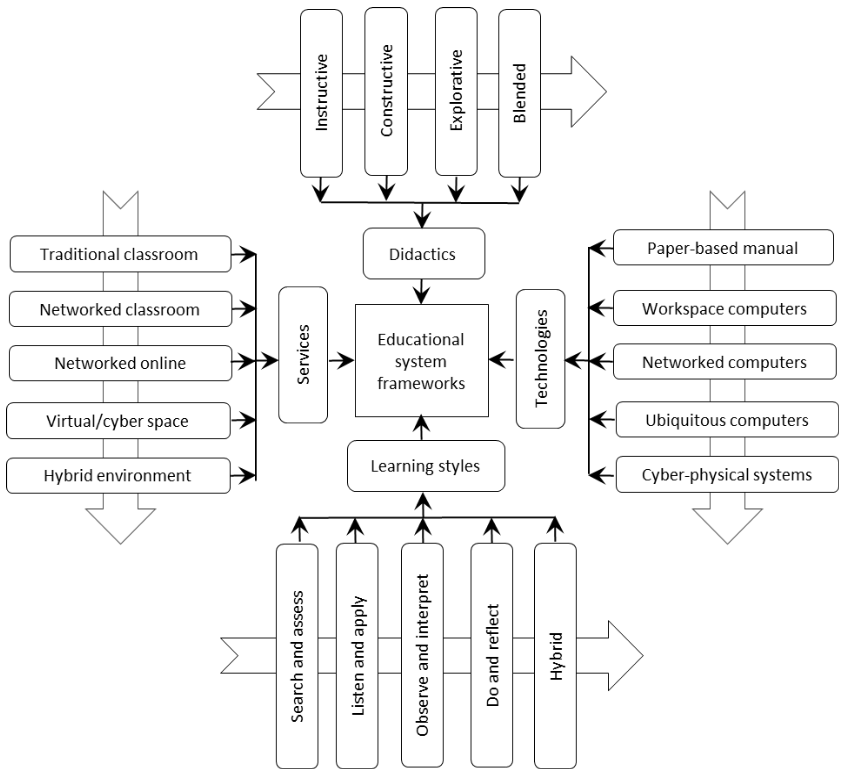

Figure 1.1: Trends influencing knowledge dissemination

of where Web3D is utilised to provide multi task problem solving systems to help learning. These systems provide both visible means and sophisticated complex movements of AR/VR rendered models. The effectiveness of AR/VR environments for education is considered more effective when special purpose hardware inclusive of haptic interface to provide feedback sensation to the user is introduced [41]. For example in the medical education domain there is a requirement to model and simulate the characteristics of soft tissue. There are surgical simulators which can mirror these characteristics using spring model or finite element method. Importing these methods into Web3D technology requires a new approach involving scalability by controlling the degree of localisation of rendered meshing [55] [42]. The introduction of AR/VR Web3D simulators into medical training is proving to be a useful tool for learning diagnostic technics.

Though many technical papers published in the fields of medical and AEC disciplines report on successful technology developments, system implementation and application, and the positive impacts, there still remains numerous open issues, many limitations and bottlenecks (e.g. in terms of real-time computation), and even disadvantages such as cyber sickness, nausea, postural instability, visual side effects, and after effects [43]. In recent years we have seen the growth of sophisticated AR/VR software development packages (e.g. SDK) providing developers with core functionalities such as (i) rendering, (ii) physics, (iii) media, (iv) scripting, (v) artificial intelligence (AI) and (vi) networking capability [44]. The physics function for example, enables the developer to simulate the applied physics such as gravity and the ballistics law. The sound, visual and animation are developed through the media function while the actions and reactions of the synthetic user (non-human) are determined by the AI function. AI is described as the ability of a synthetic user to think and react like a human user does [44]. A key element to this function is the introduction of path way finding algorithm such as the Dijsktral algorithm [45].

1.2.4. Considering human and societal demands

Evidence emerging from literature, highlights how the AR/VR developers often become embroiled in addressing the development needs thereby forgetting or compromising the needs and expectations of the end-user. From an educator user's perspective the introduction of technology delivered education increases their workload to include additional tasks such as (i) Maintenance and upkeep of the technological platform, (ii) facilitating interactive activities outside of normal hours and (iii) monitoring student online collaboration. When a new technology first emerges, there is usually a period of time required for human users to firstly understand it before applying it. The motivation when developing technology driven educational platforms tends to focus on making the technology fit familiar traditional teaching methods [46]. For example, when comparing traditional classroom based learning with distance learning using e-learning technologies the literature tends to highlight the advantages of one over the other. However, they are very different as can be seen in Table 1.1 [47].

It has taken a number of years for educators to build up the required skills that allow the practical delivery of high quality e-learning programmes [48]. Validation of technologies, such as computers, projectors, networks and electronic media, only happened when it was demonstrated to the human user how they can improve their abilities as both educator and learner [17]. Simulation is an effective and cost efficient approach to enhancing knowledge transfer, and improving performance [49]. The best example of this is in the area of flight

Table 1.1: Traditional learning versus e-learning

	Traditional learning	E-learning
Advantages	• Knowledge exchange • Skill development • Interaction between learner and teacher • Socialisation • Immediate feedback • Motivating leaner • Being familiar to both instructors and students	• Knowledge sharing • Providing any time accessibility to course materials • Adds pedagogic benefits • Cost effective for leaner • Available to global audience • Unlimited access to knowledge • Helpful for instructors
Disadvantages	• Class room size • Student teacher ratio • Accessibility • Expensive to deliver • Instructor-Centred • Time and location constrains	• Costly to produce • New skills needed • Affordability • Minimal social interaction • Lack of immediate feedback

simulators [49]. If designed and integrated appropriately, immersive and non-immersive simulators AR/VR can be applied effectively in training [50]. The drawback of the current AR/VR technology is its validity as an education tool [51]. Networked connectivity such as online video sharing/streaming and other such collaborative activities involving multiple remote users working with social interactions are popular forms of connectivity enablers [52]. Ubiquitous web-based networking is strong enough to support and provide a web-based infrastructure network that is capable of (i) receiving various types of content from the users and (ii) supporting communication among large volumes of users thereby supporting the formation of virtual communities (social or otherwise) [53].

There are numerous examples of shared AR/VR networks enabling humans to participate as actors in collaborative working and social gaming . In fact today's AR/VR networks enable both human and synthetic actors to coexist at three levels; (i) participant, (ii) guided, and (iii) autonomous. The main difference between these levels is determined if a user (synthetic/natural human) (i) has control, (ii) is controlled, or (iii) actions take place without intervention [53]. Networked AR/VR websites incorporate four technological enablers; (i) networked computer supported cooperative work (CSCW), (ii) AR/VR scene management, (iii) artificial life generators, and (iv) digital computer animation [54]. A simple architecture for networked connectivity and real time activity simulation incorporating actors at the abovementioned three levels is illustrated in Figure 1.2. Networked connectivity enablers allow multiple users to interact with each other and their virtual surroundings; (i) 3D models, (ii) animated scenarios, (iii) digital images, and (iv) recorded/streaming video.Research vision and main objectives

1.3. Research vision and main objectives

1.3.1. Research vision

The primary aim of the completed research was to develop an effective **web-based stimulated**

learning system (WBS-LS) for distributed construction engineering education by blending technological, cognitive and social enablers. This is pursued to enhance real-life personalised learning experience in the discipline of construction engineering. The motivation for doing and presenting this research came about as a result of the challenges, problems and issues experienced in relation to a specific construction engineering disciplines, which require the completion of procedural tasks to help develop problem solving skills, such as refrigeration maintenance. As a visual and audible learning and teaching aid, the design of WBS-LS is supposed to provide the tutor with realistic working models, which make it easier to describe and explain operational principles and system functions.

The literature has presented the strength of the SDK technological enabler software and opened the possibility to explore how to create an effective and robust WB-SLS, which blends technological, cognitive and social enablers. The bandwidth of ubiquitous networking is now sufficient to provide stability and reliability for web-based activities. The growth of cloud-based services will further enhance network programmes. The aspirations to design unconventional WBS-LS are fuelled by the desire to engage students in complex problem-solving by a multi-level, scenario-based learning system. The process involves presenting the learners (the student users) with alternative scenarios for real life tasks and events in construction engineering functions such as refrigeration maintenance (i.e. list the basic elements of the system or show operation process) and then integrating the context of those scenarios into constructing a set of real classroom instruction. Because of the diversity and complexity of measuring the performance of the human user the simulated learning scenarios provide case example of this diversity.

1.3.2. Main research objectives and assumptions

Construction engineering learners need to develop higher level problem solving skills to demonstrate their knowledge through procedural actions. Therefore, the concrete objectives for this research were:

- To learn more about the observed phenomena and to explain its relationships and behaviour.
- To conceptualise an approach and a framework for a novel support system
- To create a novel web-based education system that reflects the procedural actions of a real world construction engineering discipline.
- To provide a mechanism that will encourage the development of higher level problem solving knowledge gain.
- To enable learners dislocated at multiple locations to experience perceptive immersive pervasive learning.

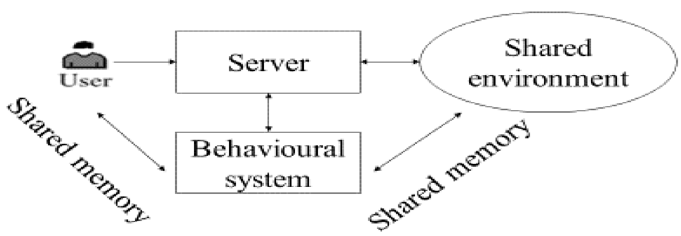

Figure 1.2: High level architecture for networked connectivity system

It is a recognized challenge in CEE to provide an efficient framework and a 'vehicle' for the delivery of the underpinning knowledge that enables both co-located and dis-located students to acquire procedural skills and to become thinkers who are capable of high level problem solving in real world tasks. The formulated hypothesis implies an in-depth investigation and utilization of: (i) cognitive enablers (perceptive/psychological), (ii) technological enablers (hardware/software), and (iii) social enablers (human interactions and reactions). The cognitive enablers are both part of, and equally spans across the two other enablers, in the form of cognitive knowledge and skills absorption. The starting proposition was to develop a web-based learning system based on the concept of blending technological, cognitive and social enablers. The conceptual function of the enablers is to produce a learning system that will (i) motivate students, (ii) provide perceived usefulness, and (iii) ensure rich knowledge transfer. In addition to functionally blending technological, cognitive and social enablers, the web-based design will need to encapsulate the principles of cyber psychology.

1.3.3. Methodological framing of the research approach

The complexity of the research project as a whole required a systematic scientific approach. For this reason the research project has been decomposed to a set of logically connected research cycles. Altogether five research cycles were completed. Each cycle was treated as a separate operational unit with its own objectives, the evaluation of the output from each cycle provided the opportunity to test the quality of the results and determine if the gap between the required and implemented characteristics of the cycle met with its stated objectives. However, the knowledge coming out from the individual research cycles was transitively used and fused. Figure 1.3 shows the decomposition and the methodological framing of research. The introduced research cycles afforded the opportunity to trace, revise and enhance research

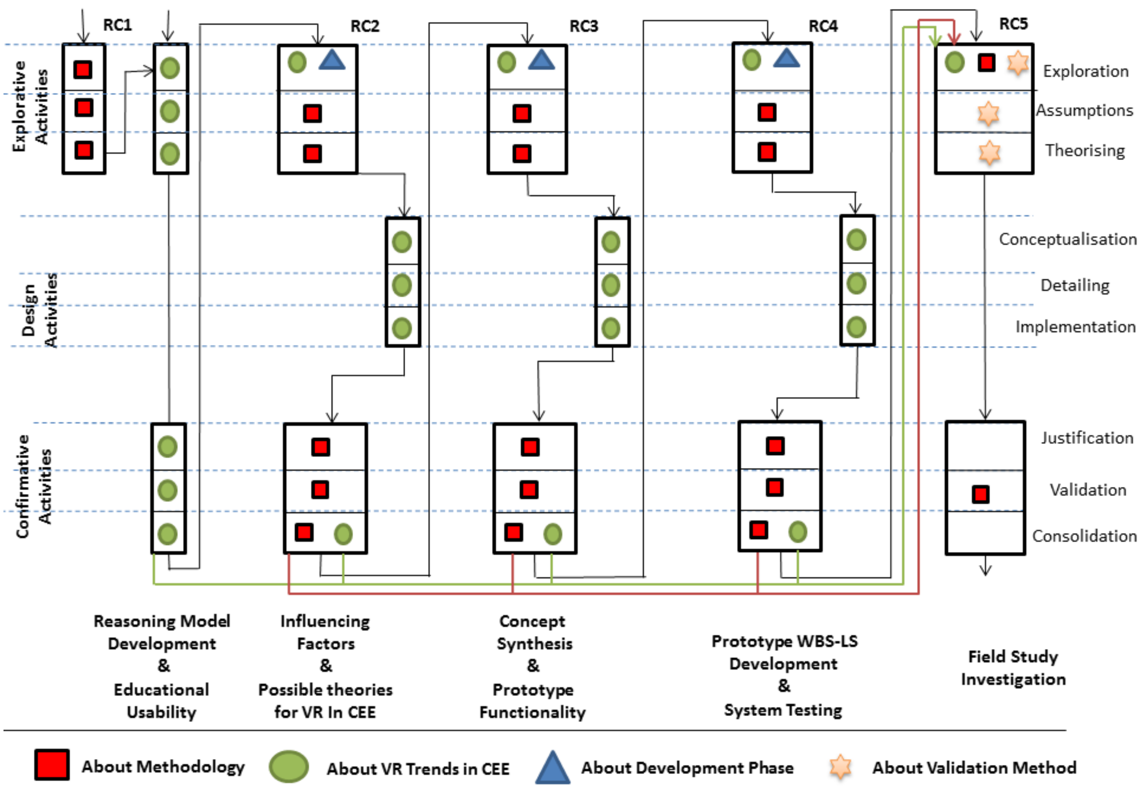

Figure 1.3: Methodological framing of the promotion research project

design decisions in each phase of the execution of the project. The applied methodological framing (shown in Figure 1.3) resolved the conflict between differing constructed definitions in various versions of theories. Thereby it supported a stronger link between the design research and the empirical research domain.

As far as the conduct of the planned research work is concerned: (i) completion of research in design context (RIDC) was based on literature studies and critical analysis exploration, (ii) completion of design inclusive research (DIR) was based on tangible theories and concepts and (iii) completion of operative design research (ODR) was based on prototype design and real world application for testing and validation. The first research cycle was mainly based on literature studies and critical analysis driven exploration in order to form a comprehensive image of the current state of the art. In the second research cycle, we explored, reviewed and analysed the literature to evaluate the influence of present day technologies on CEE. Design inclusive research was applied to research cycle 3 as it was about tangible theories and concepts identified and developed to test knowledge. The remaining research cycles were conducted through operative design research methodology framing, as it was about testing and analysis of activities.

1.4. Structure of the thesis

1.4.1. Workflow of the research actions

As explained above, the general research problem was broken down into five specific research cycles. In Research cycle 1 (RC1) we have aggregated knowledge about the studied phenomenon through an exploration and analysis of the current trends and developments in the use of virtual reality technologies and systems for CEE. In addition an evaluation of their educational usability and effectiveness was conducted. The main objective of this cycle was to obtain descriptive knowledge about what the phenomenon is, what forms it manifests itself in, and what its main characteristics are. RC 2 included an investigation of influential factors and causalities, and intended to specifically investigate the concept of using VR software packages. As a result of the research, a detailed idea concerning cognitive stimulation of procedural activities was derived. We found that software packages now offer built-in visual editors that enable the simulation of real life scenarios through animation. These software packages also promote a high level of interactivity through both social and cognitively-based virtual encounters. The fact of the matter is that the rapidly evolving software technology has forced educators (as system users) to take another look at learning space. Research cycle 3 was concentrating on conceptualisation of a methodological approach and a support system that utilizes VR as a means of providing new experiences for learners. Based on the theories deduced and validated in RC1 and RC2, a prototype of the WBS-LS was implemented, which made it possible not only to test the applied design principles, but also many more aspects of the stimulating virtual learning environment.

The research data from RC1 and RC2 provided evidence that emphasis on technology-lead education tends to introduce overly bias towards the process and technics aspects of building a VRE. Consequently, our goal was to achieve a balanced solution. Therefore, we have explored the possibilities of using freeware software to create a web-based stimulator that is able to engage the learners (student users) cognitively, socially and affectively. RC 4 operationalized our design approach and developed the WBS-LS into a testable prototype. The built WBS-LS prototype virtually replicates the content of learning and the process of actions typically conducted in a refrigeration training laboratory. We used the prototype for testing multiple, unpredictable scenarios and to confirm if we managed to address the pedagogical and technological challenges of self-managed, learner-centred, dis-located web-based learning. RC 5 was dedicated to testing the working of the functionality of the prototype, the usability of the prototype in a real life context, and the utility of the WBS-LS through the performance of the learners. At testing the usability of the prototype, we compared the theoretical expectations with the concrete empirical observations, evaluated the influencing factors, and identified key performance indicators to measure the level of reliability of the obtained results.

1.4.2. Contents of the chapters

This thesis consists of seven chapters, which presents the work and formatted results of each of the specified research cycles. This introductory chapter (Chapter 1) provided an overview of the problem domain, defined the research needs, the research objectives and assumptions, and described the methodological framing of the research project. Chapter 2 presents the main focus of RC1, which aimed at providing descriptive knowledge about what the influencing factors are. This involved identifying data from (i) a state of the art literature review concerning the application of VR technologies in CEE, (ii) an analysis of the current trends and developments in current virtual reality technologies and systems and an evaluation of their educational usability and effectiveness. Chapter 3 discusses RC2, which concentrates on the main causalities based on assumptions that (i) researchers are investigating the concept of using VR for a number of decades, (ii) it is now possible to simulate real life scenarios, (iii) AR/VR can now promote a high level of interactivity both through social and cognitive based virtual encounters, (iv) digital learners use technology as a foundation base for everything they do (v) they read web page content and digital social media content more frequently than they read from hard copy text media and books and (vi) they have to be multitaskers to use multiple software platforms to interact between the real and the digital world.

Chapter 4 presents the work in RC3, which focussed on the conceptualisation based on the theories deduced and validated in RC1 and RC2, a proposition to apply a conceptual theoretical design framework that involves the blending of theory sets (i) cognitive enablers theory, (ii) technological enablers theory and (iii) social enabler's theory was explored. The research data from RC1 and RC2 provided evidence that current technology lead education for CE tends to be overly bias towards the use of software and the development of the technology platform thereby neglecting the pedagogical support needs for the learners. This chapter presents the vision to develop a complex stimulator consisting of multiple unpredictable events that both engages the users' cognitively and affectively, while enhancing their problem-solving skills within the construction engineering discipline of refrigeration. This conceptual design was proven to be novel. Chapter 5 describes RC4, the focus of which was on the development of a testable prototype. The multi-enabler-based WBS-LS is designed to address the current pedagogical and technological challenges of self-managed socialised on-line learning of construction engineering students and intends to reproduce an immersive environment that offers a student-centred knowledge and skills acquisition approach. Included in this chapter is a description of the design process that produced an enabler design framework to assist learners to develop problem-solving and higher level thinking skills when presented with unfamiliar scenario problems.

Chapter 6 describes RC5, which focused on a field situated experimental study, a real student cohort are selected. RC5 concludes the entire research. At this point the theoretical expectations are compared with the empirical observations and the influencing factors are evaluated. This practical justification process is conducted as a real-life implementation Beta experience. This makes it possible to test the impacts of the proposed system and application of the design framework. The dual objectives of this part of the study are to test user performance with the system and overall user satisfaction. Chapter 7 summarises the findings from each of the research cycles and presents conclusions about the enabler-based framework and prototype system. It also discusses future possibilities and considers if this framework has the capacity to continue to evolve.

1.5. Related own publications

1.5.1. Journal article:

[1] Keenaghan, G., Horváth, I., & van der Vegte, W.F., (2015). Enhancing real life expertise in construction using virtual environment simulation. *DIT Level 3 Journal*, 13(2), (pp 66-74).

[2] Chenaux, A., Murphy, M., Keenaghan, G., Jenkins, J., McGovern, E. and Pavia, S., 2011. Combining a virtual learning tool and onsite study visits of four conservation sites in Europe. *Geoinformatics FCE CTU*, *6*, pp.157-169.

1.5.2. Conference papers:

[3] Keenaghan, G., & Horváth, I., (2014). State of the art of using virtual reality technologies in built environment education. In *Proceedings of the Tenth International Tools and Methods of Competitive Engineering Symposium (TMCE 2014)*, Vol. 2, Budapest, Hungary, (pp. 935-948).

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[5] Keenaghan, G., Horváth, I., & van der Vegte, W.F., (2015). Developing an edugame simulation application for engineering: It works in practice, but will it work in theory?. In *Knowledge Management Symposium Conversation Café, Dublin, Ireland, 26-27 March 2015*. Dublin Institute of Technology, (pp. 1-10).

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Chapter 2

Research cycle 1: Aggregation of knowledge concerning the research phenomenon

2.1 Introduction

2.1.1 Objectives of knowledge aggregation

The general objectives of this research cycle (RC1) was to explore the state of the art of enabling hardware, software and cyberware technologies of screen-based learning systems applicable to construction engineering education (CEE). The purpose of this was to better understand the phenomenon and to identify the knowledge gap with regard to this. The specific objectives were to aggregate knowledge and to consider it from: (i) a human learner aspect, (ii) a social causality aspect (iii) a learning technology aspect and (iv) a learning environment aspect. Our initial focus started with investigating the number of (i) technology screen-based education systems that represent real world construction actions, (ii) at the same time enables dis-located students in multiple locations to experience networked connectivity, (iii) offer visual and verbal communication, (iv) provide a mechanism to encourage the development of higher level problem solving and (v) enable pervasive learning. The need for this investigation is rooted in the necessity of keeping dislocated construction engineering students engaged in procedural activities normally carried out on site by their co-located peers. The main guiding questions to focus the extensiveness of our literature review was:

- What are the main design features for a web-based stimulating learning system, which uses the widely accepted screen-based technology to promote higher level problem solving ability?
- What are the design requirements for this type of web-based learning system if it is to meet the technological, cognitive and social challenges present in a modern learning environment?
- What didactic supports and learning theories are required to enable these learning systems to efficiently assist dis-located learners to maximise their procedural skills and knowledge gain?

A review of literature back to the 1930s, uncovered the long-time ongoing debate about traditional versus progressive education [1]. This issue was put in a modern context some four decades ago. How to design and build digital computer-based learning systems for progressive education and for a mobile and transient population of digitally literate learners? This is not only an issue, but also a challenge that is perpetually exercising the minds of educationalists, policy makers, educators, and learners. The motivation is twofold: (i) to overcome the generation divide, and (ii) to profit from the continually improving digital literacy of mankind.

2.1.2 Introducing the applied reasoning model

Social science/education research literature is extremely broad. The phenomenon of learning support systems have been addressed by researchers/experts of many knowledge disciplines. Aligned with the objectives of this research cycle (as outlined in Chapter 1), a reasoning model has been devised, which reflects our view on this extremely broad field of knowledge and research interest, and which presents the specific knowledge domains that were of importance for the explorative part of this research. This reasoning model is shown in Figure 2.1. The existing body of research suggests that the major trends, as identified in this reasoning model, are towards exploring: (i) how next generation learning systems should manifest, (ii) how to be inclusive of social media, and (iii) how the manners of human learning and socially interacting are changing and will continue to change in the future [2]. The available and emerging enablers (technological, social and others) provide the foundations upon which knowledge, assumed as meaning and understanding, is constructed through socially enabled means, and accessed through technologically enabled means [3].

Modern society is now made up of a large amount of people who use technology-enabled means in their daily professional and social practice. As a result, the technologically literate society has broadened exceptionally. This includes, among many other things, the rapid development of screen-based simulation approaches for educational purposes. As a consequence of the technological progress, many different implementations and utilizations exist ranging from entry-level desktop tools and applications through immersive portable means to high-end immersive, multi-media, computer aided virtual environments (CAVEs) [4]. Head-mounted displays (HMD are commonly used devices to provide visual interface for users. However, CAVEs are still used in large-scale industrial and academic applications in

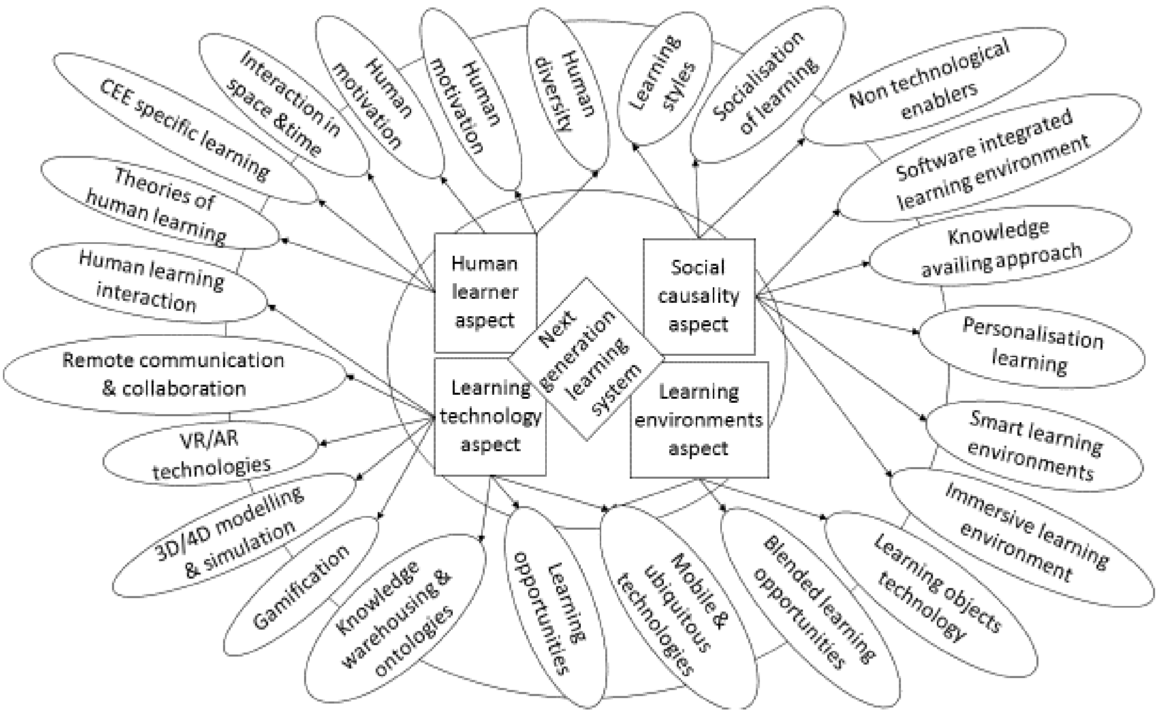

Figure 2.1: The applied reasoning model

which images are projected onto the walls, the ceiling, and the floor of 'artificial spaces' using various projector technologies [5]. The visual simulation of the displayed contents is based on 360 degrees of vision through the viewer lens.

Such technological advancements have resulted in the concept of 'virtual construction' that is becoming widely accepted in the construction industry [6], but also in other fields of application. CEE scientists have done research in the concept of using screen-based simulation technology for a number of decades. The past few years have seen an explosion of new knowledge and data in this applications domain, and various theories have been proposed by researchers concerning the influence of human factors [7]. Numerous examples can be found in the literature highlighting the influences that this family of technologies has on the development and daily practice of CEE [8].

2.1.3 The research approach

We have previously mentioned that there is a growing body of literature that monitors and investigates how the introduction of technological enablers into our daily lives in a large scale is contributing to how modern society is learning. These studies have highlighted both the positive and negative effects of introducing specific technologies. However, they are restricted to the past and the emerging situations, but cannot obviously address the situation in the near and far future. In particular, they quite comprehensively considered the experiences and possible impacts VR/AR screen-based applications are having on CEE [9].

As outlined in Chapter 1, the first part of RC1 was explorative in nature. The initial objective was to gather knowledge about the most recent stages of development of screen-based learning systems and their introduction in the CEE practice. To achieve this objective, we conducted a desktop survey and collected literature that provide information on (i) what kind of simulation orientated learning systems are being applied in CEE and how they are applied, (ii) what manifestations such systems have and how are they implemented, (iii) what the current enhancements are, and (iv) what the open issues exist and what opportunities are in the respective knowledge domains. The second part of RC1 was confirmative in nature, and targeted the testing of the research theory derived based on the literature study and the investigation of its implications. The overall outcome of completing RC1 was a reliable descriptive theory and clear research motions for RC2. RC1 was divided into aggregation, induction and deduction stages ensuring analysis, hypothesising, testing and comparison of knowledge data, to provide comparable reference data that remain within the scope of the hypothesis. This helped to develop a deeper understanding of the studied phenomenon.

2.1.4 Overview of the challenges of doing this literature study

A notable challenge is that (for the time being) just a small minority of construction engineering educational professionals are using or introducing educational technologies into their daily practice, apart from a number of showcases. The majority of them is stacked with the traditional means of learning and teaching [10]. The idea that students may take control and manage any learning system far better than the educators, makes them typically nervous. Convincing educators to change their practice and to include the level of the students' digital literacy as part of their professional development will take time. This manifests as a large cultural and attitudinal challenge that was posed also to the author of this thesis. Nevertheless, various studies associated with the field of CEE highlight the necessity of having various technology-enabled systems for the following reasons:

- the growing complexity of construction engineering tasks,
- the need for optimisation of the measures to approach construction as a manufacturing process (time, cost, quality, impact),
- the demand of optimal utilisation of resources and assets (expertise, competencies, staff, high-tech equipment, software tools), and
- the on-going globalisation and division of labour and knowledge. .

Another challenge is the need for a multidisciplinary design approach if technology-based learning systems are intended to be an outright success. For example a number of cross-sectional studies confirm that collaborative research projects involving educators/social scientists and computer scientist can address phenomena such as the use of technological enablers (including mobile, ubiquitous and even cyber-physical computing powered devices) to improve and enhance the learning and teaching experience [11]. Technology-based learning systems have often failed to meet their set objectives because of learning and teaching inefficiencies, which are typically caused by the fact that the design of some learning systems do not take into consideration the differences in the attitudes of the learners and their learning style [12]. De Matos et al. advocated the use of technological enablers combined with learning theories (cognitive enablers) as a means towards the creation of pervasive learning systems [12]. Nguyen and Hung introduced the concept of a new ‘model for learning’, which placed the emphasis on the holistic and procedural practice [13]. Chang and West discussed this new model for learning as a ‘digital ecosystem’ that goes beyond ‘traditionally defined collaborative learning environments’ [14]. They deliberated over the main key elements of a digital ecosystem for learning and provide numerous examples for consideration. Coupled to this is the additional challenge for monodisciplinary researchers to realize the concept of an augmented reality smart campus. In this environment, online social interactions are supported by the paradigm of object orientated programming of learning objects (LO) and virtual reality (VR) spaces [15].

In spite of the challenges mentioned above, Fischer argued that the most difficult of all of the challenges is not the actual ability to provide learning systems that utilise screen-based technology, but rather the challenge has more to do with matching the information and its pace of release to the time and pace each learner is ready to receive it [16]. On the other hand Beetham believed that there are many more difficult challenges about the learning activity design for the learning system application [17]. Accordingly, there are many components loosely derived from activity theory which could be applied to learning activity design (Figure 2.2).

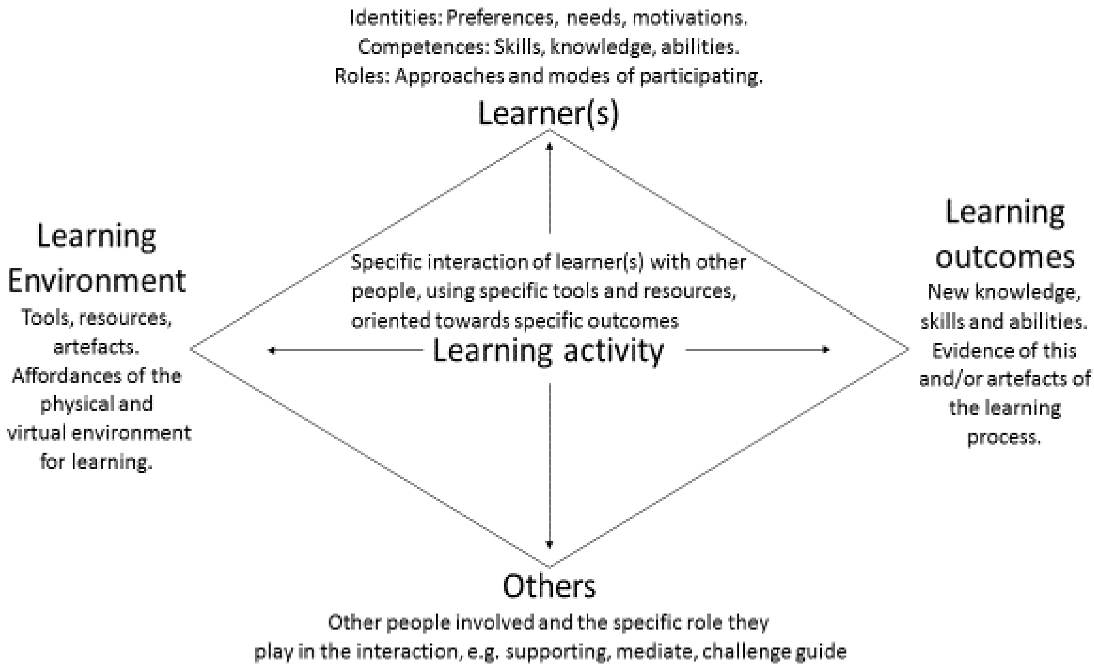

Figure 2.2: A generic outline of learning activity [19]

Again another notable challenge is the rapid development and integration of screen-based VR/AR technology for CEE as observed from a number of case studies. In the period from 2005 until 2016, VR/AR technologies have moved closer to standardise software systems and, as a result, there is a greater demand for their integration with modelling software nowadays [18]. Ellaway confirmed that the use of VR/AR simulators is already well established in technical, professional and vocational education. The studied publication explained in which sense today's view on technology-based learning differs from tomorrow's approaches to learning systems [19]. These learning systems will no longer be specifically about the technology, but will concentrate more on the activities and experience that the technology provides [14]. The current range of technological enablers extends from visual and audio through tactile, haptic and limbic to brain, cognitive and stimulation [20]. At this moment the research shows that there are still numerous open issues, many limitations and bottlenecks (e.g. in terms of real-time computation), and even disadvantages such as cyber sickness, nausea, postural instability, visual side effects, and after effects [21].

Notwithstanding, the technological resources and the cognitive design approach are also remarkable challenges of designing a learning system that incorporates all constituents of the social design approach. Socialisation design theories stated that learning is fostered when individuals encounter experiences and demands that they cannot completely understand or overcome [22] [23]. As a result, the learner must work with peers to comprehend and master the new or unfamiliar. Ruble, a developmental psychologist, worked on the theory that learning growth and developmental changes are stimulated by events that put individuals into new social surroundings involving uncertainty and requiring newly learnt knowledge [24]. The digitally literate learner's approach to social interactions, computer interaction, and motivation to learn may appear (at least on the surface) to be radically different from the inspiration of previous generations. However, it must be noted that the common denominator that binds all generations together is the human factor.

2.2 Findings concerning the human aspects

2.2.1 Modern theories and approaches to human learning

Modern learning systems exploit learning theories such as constructivist theory (that is, roughly, how people learn). The perspective of this theory centres on what is accepted as a means for knowledge gain. Learners create knowledge from interacting with each other, society, groups and organisations. The constructivists view new knowledge as knowledge, which is added to the existing knowledge of learners. The process of knowing, decision making, planning and problem solving is learning, which occurs at all levels (individual, society, group and organisational). The constructivist theorists, such as Piaget, Candy, Dewey, Rogoff, Von Glaserfeld, Vygotsy, Bruner, Boud and Illeris, believed that knowledge is constructed as we learn [25]. Learning is not seen as understanding the true nature of things but it is seen as a social and personal construction of meanings, resulting from day to day interactions being interpreted by the individual learners or a group of learners.

The constructivist approach to teaching tends to favour situated learning and community of practice. One side of the argument is that social interaction and collaboration are essential components of situated learning, learners become involved in community of practice [26]. The other side of the argument for situated learning theory place an emphasis on the idea of cognitive apprenticeship [27]. This is learning which is supported in a domain that enables students to acquire, develop and use cognitive tools in an authentic activity, both in and outside of a learning environment. Situated learning is related to Vygotsky notion of learning through social development [28].

Bonk and Reynolds provided an alternative theory to human learning. They advocate instructional strategy, that is, the setting of challenging activities to force the learners to develop their cognitive abilities and to improve the overall quality of the learning [29]. On the other hand, Kozma brought forward an argument that, when presented in the form of 3D animated VR, screen-based technology has the strongest influences on the quality of the learning [30]. Cognitive psychologists defined human learning as the study of how information is sensed, stored, elaborated and retrieved [31]. How learning takes place is subject to the viewpoint of the learners and their learning style. Modern approaches to learning define human learning as a process that leads to change.

Laurillard pointed out that if present day learning systems are to change from what is currently being offered, it must be a collaborative learning process (community of practice) that drives this change and not the technological hardware and software developers increasing appetite to build applied cyber physical systems for learning [32]. Ravenscroft argued that in order for screen-based computer simulation to truly transform educational practice, the roles of the stakeholders in conjunction with the roles of the enablers must be examined [33]. Engaging in an evaluation process affords the learner and educator (community of practice) the opportunity to contribute to the effectiveness of educational delivery. Our experience is that the literature has not specifically addressed the issue of learning experience when different technologies are applied, but it has emphasised the importance of evaluating the usability of learning systems to test and enhance the effectiveness in applications. As a result it is our contention that the success of any learning using AR/VR screen-based simulation as a technological enabler to disseminate knowledge, needs to blend cognitive and social enablers as part of the learning system design.

2.2.2 Learning in the field of CEE

CEE involves a large amount of procedural/professional practices, each of which needs a set of skills. In the near past, these skills have typically been taught and practiced according to a limited number of appropriate learning theories. These were used to form the andragogic framework for knowledge transfer. Instructional design, social learning, work-based learning, situated learning, activity learning, intelligences, or project based learning are the main learning theories applied to CEE practice [34]. Numerous third level learning systems developed for CEE expose the learner to a number of these (above-discussed) learning theories as a means of helping learners form a deep understanding of the procedural/professional practices as applied to construction engineering. The construction engineering industry also agrees that learning on the job is a lifelong process. With the continued growth in technologies and the ever increasing ease of access to information via smart handheld devices and ubiquitous internet connectivity, traditional means of learning and knowledge transfer have evolved and will continue to do so for the foreseeable future.

The literature presents many reports on experiments with screen-based technology-enabled learning systems, which are supposed to fulfil the industry needs [170] [35]. To capture the integral results of the many successfully conducted experiments the term 'virtual construction' was coined [36]. Virtual construction refers to the industry practice of increasingly using 3D modelling software to build VR versions of concept construction designs. This adds to the fundamental challenges for CEE and has forced educators to take another look at learning didactics [37]. As a consequence, CEE educators are being faced with the challenge to ensure the appropriate learning theories with respect to the application of virtual construction technologies-enabled learning contents simulations [38].

2.2.3 Human diversity issues

Human diversity is a major consideration for all forms of education and must be accounted for when developing technological based learning systems. Social virtual simulation technology and one click anywhere any time mobile accessibility has added to human diversification and their diverse social habits. Bringing groups of learners together (with each of them having individual needs) to form learning communities of practice requires some form of human diversity management [39]. Human diversity is an equally important issue for online dislocated modes of education as well as for traditional classroom-based education. There are numerous studies highlighting the aspects of understanding and handling human diversity in the field of psychology. In general, the completed research has resulted in a cluster of conceived theories about intelligence, personality and learning styles. Typically: (i) individual, (ii) collective, and (iii) population diversity are differentiated as categories. Hall (cited by Hiles in [153]) has classified the aspects of human diversity as: (i) class, (ii) gender, (iii) ability/disability, (iv) age, (v) sexuality, (vi) race, and (vii) ethnicity [156]. Proactive learner-to-learner and educator-to-learner interactions among individuals of diverse demographic cohorts has proven to bring about positive academic achievements. This can be attributed to the influence that such interactions have on the awareness of the self and of others, which decreases the attitudes of prejudice [154] Different diversity management mechanisms have been introduced into education programs. Part of this mechanism includes providing the means and encouragement for active participation of the members of the learning community. Evidence from the literature indicates that educational programs, which facilitate the exchange of diverse perspectives, ideas, experiences and identification of needs enhance the educational experience of all learners [155].

Delivery of distant learning education through a technological based learning system assumes the learners are proactive by nature with an already developed skill to for independent study [40]. Technology based learning have played a role in the shift from an emphasis on teaching towards the current emphasis on learning as an approach to today's forms of higher level institute education. The fundamental combination of andragogic and learning theory supports required for each individual to ensure they are motivated to seamlessly progress through an interactive social and collaborative learning space, is not yet fully explored for the discipline of CEE and therefore requires further in-depth analyses

2.2.4 Human experiences and motivation

The assumption concerning the use of screen-based learning systems is to provide a learning environment that (i) permits engagement with a subject matter, (ii) allows for individualism, (iii) caters for a varied learning pace and (iv) provides instant access to large amounts of information. Screen-based technological enabled learning systems can and do provide challenges to test learners understanding [19]. As discussed by Rahimi et al., there has been a shift towards proactive and context-sensitive personal learning environments [16]. This shift entails the change in the role of learners within the educational process. This has in turn raised the need for modelling of: (i) the learner role, (ii) the virtual learning processes, and (iii) the relationships to content, media and peers. Our observation is that these models have appeared in the literature as meaningful proposals for individual (self-standing) aspect models rather than is a meaningful integration (synergy) of aspect models.

Learning through web-hosted and socialised screen-based learning systems offers a very different experience in comparison to classroom-based learning. Promoted through mobile devices-led social virtual encounters, screen-based technological enablers have by now reached a high level of sophistication,. The level of development and sophistication of these advanced visualisation systems is so high that, when they are applied to a learning environment, they can indeed contribute to significant enhancements over the traditional education methods, and therefore, can provide better experience for a variety of learners. On the other hand, according to Watson, the issue of learning experience when AR/VR technological enablers are used has yet to be addressed scientifically [41]. According to Salmon, experiences to date have resulted in an expectation for online access that it should be quick and easy, and in the understanding that motivation is dependent on engaging content and context [42]. Through the use of mobile devices learners can instinctively expand their learning environment into their virtual social networking world, which in turn may further motivate them to get engage with and take charge of their own learning [42].

2.2.5 Interaction in space and time

Traditional means of conducting distant learning and providing educational materials did not address the issues originating in the facts that learners were often isolated from the educators as well as from their cohort over long periods of time. In an effort to resolve the issues associated with being isolated as learner, the role of technologies was recognized a long time ago. Typically technology was used not only to establish communication, but also as a means to improve the didactics of knowledge delivery, to optimize the learner/educator relationship, and to minimise the isolation periods associated with distant learning. In addition, the integration of technology can enable providing reassurance to the learner that they are regarded as independent (autonomous) members of a learning community [43]. Investment in the development of screen-based learning systems by the military and medical professions has demonstrated the positive potential of using AR/VR for training learners who have a need to develop problem solving skills. Table 2.1 summarizes the number of professions currently utilising and benefiting from AR/VR screen-based simulation training environments. Sawyer and Smith, formulated this taxonomy table based on two axes, namely audience and purpose [44].

Stemming from these screen-based learning systems is a considerable amount of literature highlighting the importance of an intuitive screen-based interface design. This literature mainly relates to how it has an influence on human-computer interactions (HCI). Shneiderman argued that a well-designed HCI must provide informative feedback, permit easy reversal of actions, support an internal locus of control, reduce working memory load and provide alternative interfaces for novice and expert users [45]. When an interface is well designed humans are highly tuned towards images and graphics [46]. Learners using AR/VR screen-based learning systems are supposed to master the interface design in conjunction with learning the new knowledge if they are to invoke cognitive growth. Like concerning human experiences and motivations in the context of present-day learning and teaching, the literature also rich with regards to person-person, person-system, system-person, and system-system interaction. However, it is practically impossible to consider all relevant aspects and their interrelationships in this Sub-chapter.

Table 2.1: The taxonomy of computer generated simulation (originally published in [44] as work in progress)

	Games for Health	**Advergames**	**Games for Training**	**Games for Education**	**Games for Science and Research**	**Production**	**Games as Work**
Government and NGO	Public Health Education & Mass Causality Response	Political Games	Employee Training	Inform Public	Data Collection/ Planning	Strategic and Policy Planning	Public Diplomacy Opinion Research
Defense	Rehabilitation & wellness	Recruitment & Propaganda	Solider/ Support training	School House Education	War-games/ Planning	War Planning and Weapons Research	Command & Control
Healthcare	Cybertherapy/Excergaming	Public Health Policy & Social Awareness Campaign	Training Games for health Professionals	Games for Patient education & Disease Management	Visualization & Epidemiology	Biotech manufacturing & design	Public Health Response Planning and Logistics
Marketing and Communications	Advertising Treatment	Advertising marketing with games product placement	Product Use	Product Information	Opinion Research	Machinima	Opinion Research
Education	Inform about Diseases/Risks	Social issue Games	Train Teachers/ Train Workforce Skills	Learning	Computer Science and Recruitment	P2P Learning Construction Documentary	Teaching Distance Learning
Corporate	Employee Health Information and Wellness	Customer Education & Awareness	Employee Training	Continuing Education & Certification	Advertising/ Visualization	Strategic planning	Command & Control
Industry	Occupational Safety	Sales & Recruitment	Employee Training	Workforce Education	Process Optimization Simulation	Nano/Bio-tech design	Command & Control

2.3 Findings concerning social aspects

2.3.1 Socialisation of human learning

According to various authors, modern learning involves socialization processes, and socialization is claimed to be the process of learning. Actually, socialization of learning is the process by which learners of various ages learn the characteristics of the norms, values, attitudes, and behaviours of their cohort. In the course of this socialization process in learning, not only the social knowledge, but also the personality of the learners develops. The personality of learners is comprised of patterns of behaviour and ways of thinking and feeling that are distinctive for each individual. Most importantly, in the context of modern learning, it also involves and enables social construction of reality, or what people define as real because of their background assumptions, acquired knowledge, and life experiences with others. There are three forms of socialization identified, such as: (i) primary socialization, (ii) secondary socialization, and (iii) tertiary socialization, which also represent levels and which are subsequentially building on each other. Primary socialization typically begins at birth and moves forward until the beginning of the school years. Secondary socialization takes place in later childhood and adolescence, when pupils and students begin their schools and come under the influence of non-family members and, in particular, of members of their cohorts. This raises their awareness towards social expectations, the need for performance and collective inquiry and creation. The third level of socialization includes acting in a multitude of social framework at college, university and/or workplace. They have to learn and practice a variety of adult roles and adventures. The learners pick up and adapts to new roles according to the external needs and internal desires. Fast and robust socialization contributes to their success and learning experience. These dependences should be taken into consideration at developing socialized educational programs.

The above consideration is explicitly reflected in the field of CEE. For instance, successful completion of real world construction project is strongly dependent on both the physical and the social conducts of problem solving activities. The current advancement of technological enablers provides many opportunities to incorporate social aspects in the development of web-based online learning systems, which in turn, as disclosed above, offer further opportunities for socialization in learning. Thus, a prerequisite is to investigate and utilize the fundamental principles of socialisation in the development of screen-based learning systems. Technologically enhanced social enablers can now play a vital role in the creation of socialized and cognitively stimulated learning. The sort of problems that are to be addressed simultaneously in the real world environment of the construction industry is very much differs from the processing of ideas which emerge solely inside somebody's head. Extensive research has shown many examples of the roles that screen-based learning enablers may play in storing and making information available, and therefore contribute to self-construction of knowledge by learners [47]. However, examples of including social enablers as complements of technological enablers in systems are still limited and incomplete. Notwithstanding, some authors claim that screen-based virtual simulation of the happing's in real life has proven effective in fostering socialisation of human learning [168] [48].

2.3.2 Collective, remote and peer assisted learning

Research offers evidence that the learning outcome at all levels of education is higher if learners collaboratively solve problems and improve their learning opportunities. This collegial relationship not only produces creative and satisfactory solutions to problems, but also strengthens the bond among learners and educators and learning peers, and increases commitment to improvement efforts. The consideration of the necessity of socialization can be recognized in the practice of current collective, remote, and peer assisted learning. Lawson (2000) proposed a distinction between two interpretations of collective learning, in which 'collectiveness' of learning is conceptualised either as 'learning within an epistemic community' or as the 'system learning' [157]. He pointed out that in the first case the focus is on the manner in which individuals learn in virtue of being members of a particular community, i.e. through social interaction, by transforming the existing ideas, and conceptions with which they are confronted. In the second sense of collective learning, which is referred to as system learning, the emphasis is not so much on what the individuals learn, but on the processes by which the successes and failures that individuals experience become (continuously) encoded in the routines and practices of the collective of which they are a part of.

Distance learning originally meant off-line learning. According to its modern interpretation it is the process of taking courses online from a college or educational organization located anywhere in the world. The distance makes no difference any more, and the quality of education is supposed to be similar to that of a regular classroom environment, as long as the educational institution is certified by an appropriate licensing board. The remote learning is usually used as a synonym of distance learning. In this form of learning, the learner is supposed (i) to independently motivate himself or herself, (ii) to receive weekly teaching and assignments, (iii) to login when required, (iv) to do the assignments during the week, (v) to communicate with other students if asked, and (vi) to learn enough to pass any tests or exams, as described in the website[2]. It is also discussed here that it requires independence and self-motivation, time management, and the ability to block out the distractions from home.

Peer assisted learning is an approach of peer mediated instruction, whereby learners work together to support each other's learning. The technique is a catalyst to increase learner to learner and educator to learner interactions. It equally helps with learners becoming more aware of other learners level of useful knowledge and experience which directly contribute to the overall quality of learning [50]. Peer assisted learning falls under the constructivist learning theory and is a method adopted to guide learners towards developing the skills required to become independent active learners [51]. Technology based learning systems for remote learning need to ensure the learner to learner activities are supported if the quality of learning is to remain upheld [52].Techniques such as peer assessment is rapidly growing in third level educational programmes that have an online learning element to them. Researchers argue how peer assessment is beneficial to remote learning technological based learning systems [49]. With the emergence of online (remote) learner centred learning systems comes the introduction of peer to peer assistive learning.

2.3.3 Perceptive, cognitive and social enablers

The literature has proven that the introduction of screen-based technology enabled learning systems to CEE can have a positive and practical influence. On the other hand it raised

[2] http://distance-learning.yoexpert.com/distance-learning-101-7063/what-is-the-difference-between-remote-or-distance-2897.html

important andragogic questions such as:

- If the real world CE problem solving scenarios are replicated in an AR/VR screen-based computer-generated learning contents simulation, how can the andragogic supports, such as the psychological principles of learning, and cognitive, perceptive and affective dimensions, be included in the design of the delivery platform?
- How will these andragogic supports provide for a more interactive and reactive learning experience that leads to higher order thinking and problem-solving skills?
- Is there merit in drawing on communications and networking technological enablers used intuitively by young CE learners when thinking about the platform design, rather than thinking about andragogic theory in the traditional sense?

What is known from the literature is that the younger generation of learners are digitally-savvy and seem to learn effectively when multiple senses are engaged in the task. These digital learners frequently spend hours playing screen-based computer generated simulation (CGS) video games, often returning to the same game over and over. They invest huge amounts of leisure time and energy in mastering complex game rules and strategies [53]. As a result of the time and energy digital learners devote to playing such games, it is appropriate to explore the power of these forms of CGS technological enabler platforms, have to motivate and engage users. With regards to how to design a web-based distant learning system for dis-located learners, the literature suggests applying the learning theory based on andragogic principles [54]. It is also argued in this reference work that for web-based learning the theoretical perspectives of behaviourist, constructivist and collaborative learning are more advantageous. They can in practice be combined in a web-based learning design model and applied accordingly.

2.3.4 New knowledge availing approaches

AR/VR visualisation provides learners with an opportunity to work with models of the real world environment in a virtual world. This in turn is intended to stimulate cognitive skills growth. The simulation of procedural tasks gives the learner a chance to develop and refine their skills on a cognitive level through repetitive practice in a learner-centred highly socialised pervasive and ubiquitous environment [55]. When interacting online individual learners have their own perspective and experiences whereby they construct their own interpretations of the knowledge provided to them [56]. The application of AR/VR simulation for education happens for two reasons; (i) presentation of educational content, and (ii) facilitation and delivery of educational process.

The results obtained by many researchers indicate that both the CEE and construction industry sectors are experimenting with a wide range of computer supported technologies. There is also strong evidence that AR/VR screen-based simulations have positive effects on both the education sector of construction engineering and its professional and technical sectors. We found in the literature that just a limited research is focusing on what the optimal cognitive and social support systems are for implementing screen-based simulation as a means of the dissemination of knowledge and to assist learners in developing higher level thinking capabilities.

2.3.5 Personalisation of learning programs and approaches

Screen-based simulation for CEE needs to be designed with a learner centred approach that blends the cognitive, affective and social cultural domains. The use of learner centred didactics should be monitored and measured to ascertain if, when used in the correct context, they can enhance educational performance of the learners [57]. The rapid advancement of technological enablers provides an opportunity to investigate and confirm the fundamental principles of AR/VR screen-based simulation for knowledge dissemination and effective learning. It is no longer appropriate to expand the knowledge base by reporting how such technological enablers have been applied to different aspects of virtual simulated learning scenarios.

We also need to consider that individuals may forget certain chunks of knowledge: (i) because of the duration of time between learning and recalling, (ii) due to a natural memory wastage, (iii) for the reason of making place for new knowledge, or (iv) as a consequence of the natural ageing of the brain [60]. To be in line with the constructivist theory, we must accept that new knowledge is built upon already existing knowledge. On the other hand, the trend of lifelong learning has fuelled the emergence of pervasive learning approaches trough mobile technological enablers. The fact of the matter is that mobile and pervasive learning environments have the capability to recall information for the learner when they initiate a search via their hardware device, and even to store data in various memories in a personalized manner. The benefit for future learning is that technology actually makes it possible (i) to store all information needed and processed by a learner, (ii) to optimise it as personalized learner knowledge, and (iii) to recall it even a long time after it was acquired. In other words, mobile technology facilitates learners to learn precisely what, when and where is needed [58]. Mobile and pervasive computing has also introduced new ways for learners to interact with technology. An example of which is the growing use of Fitbit™. This involves wearable technology networked to mobile phone and backed up by a main server (cloud or desk top). It collects and stores personal data and helps learners to get to know how to eat healthier, exercise effectively, sleep better, and maintain optimum weight [59]. This is also a good example of how technology is collecting data personal to the user.

2.4 Findings concerning technological aspects

2.4.1 Virtual and augmented reality technologies

Advancement in screen-based simulated VR technology has in a way led to progressive development of augmented reality (AR). This is when a programmer writes script to insert digital information into a predominantly real world view using a screen-based hardware device to provide the augmented views [61]. When physical and virtual senses (visual/auditory) are combined, users have the opportunity to decide how best to interact with this type of blended world. The technology augments virtual information on top of the real world while continuing to provide the user with control from their world view perspective and their level of interactive requirements [62]. AR provides virtual objects, which gives the user a futuristic or historical real world visuals and or sounds to enhance the user's perception and interactions.

The most recent literature about the application of screen-based VR/AR learning systems for CEE, concentrate in the main, on (i) proof of concept, (ii) testing and (iii) feasibility. Recently there have been a number of prototype designs which blend modelling and game engine software to create simulated screen-based VR/AR environments for use as experiential learning and teaching aids [63]. In spite of these latest applications and experiments there remains open issues and further opportunities, all of which are heavily influenced by how the technologically enhanced learning system is perceived by the learners. Data from several studies suggest that utilising these technology enhanced learning systems as part of a suite of learning and teaching aids will match human capability if correctly exploited [64].

The literature related to the use of technological enablers to enhance CEE leaning has not yet specifically satisfied the question about how it enhances the learning experiences. There are cases where simulation VR technologies were incorporated into the design of construction engineering learning systems intended to disseminate new (to the learner) knowledge more effectively and efficiently. The research output from these case studies is summarised as follows: (i) usability evaluations were not exploited to determine efficiency and effectiveness of the technologically designed simulation as a learning systems [65], (ii) the literature at the time it neglected to specifically address the issue of learning experience, (iii) the literature at the time confirms how the software is evolving rapidly and can now animate real world construction activities and (iv) in the case of CEE the then literature highlighted the need for further research into how much added value simulated learning VR/AR applications could provide.

2.4.2 Three dimensional modelling and simulation technologies

There are a high number of cases where different AR/VR simulation screen-based technological enablers were used to deliver CEE. For example, the research of Juang was set out to use a computer generated 3D modelling software package known as Blender^{TM}. This software was chosen because it is rapidly evolving to a point where the efforts required by the novice programmer to build real world simulated learning objects is reduced and becoming more and more semi-automated [66]. Juang divided the process of developing a construction learning object into three main steps: (i) 3D model construction, (ii) set up of physical properties, and (iii) creation of interactive logic. The experiment resulted in the creation of a forklift simulation. The validation of the results carefully considered the advantages of producing learning objects that could perform functions relative to forklift driver training for a real world construction site.

The outcome of this research revealed the ‘potential of physics-based AR/VR simulation and the possibility of operating realistic virtual machines in the virtual world’. In the resultant paper published, Juang documented how the 3D modelling software provided novice programmers with a technological enabled software tool that enables (i) semi-automated programming, (ii) dramatically reduced time required to write script, (iii) good quality visuals, (iv) stability and (v) real time accuracy. The negative outcomes documented from this experiment related to clashes between solid objects (collider boundaries not been recognised), which in turn cancelled out the sense of real world representation for the learner. Inclusion of cognitive and social enablers in the design of the learning objects were not discussed. This resulted in a negative response from the learners who were surveyed. Their preferred option was for the real world classroom environment as their preferred choice over a VR environment.

The research work of El Nimr and Mohamed investigated the issue of ‘simulation modelling as an effective approach for analysing construction operations’ [67]. Construction professionals use visualisation in design, planning, implementation and delivery of construction projects to communicate the project deliverables. Their research analysed the use of screen-based VR/AR software to programme simulated visualisation of a real world construction projects from inception to final completion. This experiment considered how two different software products for modelling (Blender™ and True Vision™) could be used to develop independent 3D models and export them into one common visual simulated VR/AR environment (game engine software). This research proved that VR/AR simulation and modelling software is evolving rapidly enabling programmers to develop realistic virtual animations of construction engineering on site learning. It also demonstrated that as a result of open source, multiple platform software compatibility issues are becoming less and less. On the other hand, the abovementioned document does not discuss how these advances might enhance cognitive and social simulated problem-driven learning.

Fairuz investigated the need for 3D visualisation of designs [68]. The research concentrated on how the Torque™ software package could enhance the process used to review designs proposed for construction projects. By eliminating the need to use traditional 2D detailed multiple architectural drawings laid out on a large table within the site office. It provided detailed information on how assets were developed and imported into a virtual environment for ease of manipulation to resolve potential real world conflict and clashes. The work of Fairuz also unveiled that within the Torque™ software package is a built-in capability to reproduce code thereby repeating tedious cumbersome work by automation. The research focused on how this AR/VR package reduced potential real world conflict and thereby reduced real time building delays thus increasing construction productivity. The usability as a virtual construction tool and if the integration of cognitive and social enablers could enhance the tool as a construction learning system, was not considered in this experiment.

Lin, carried out research into the use of technological enablers to provide education about health and safety on construction sites [171][69]. As part of this research a safety inspector site tour was scripted. The software programme was used to test; (i) real world simulated health and safety learning scenarios, (ii) the level of learner centred pervasive learning, (iii) the level of learner engagement and interactivity the. The validation experiments measured the quality of learner interactions and evaluated level of (i) engagement, (ii) the level of learning interest and (iii) the type of interactivity. Upon completion the concluding findings revealed more questions rather than conclusive answers about how simulation for construction enhances the expertise and the learning experience of the learners. The pilot prototype implementation test engaged a small number (five in total) of learners and proved that screen-based simulation technology can visually represent real world learning scenarios as virtually modelled learning objects but the virtual sense of presence has yet to be perfected. This research went someway in measuring the learning experience and motivation of a small group of construction learners. It acknowledged the need for further research to measure the added value AR/VR simulated learning provides.

The research of Han, considers managing the combined impact of variability and interdependency on construction performance [70]. His analysis of a game termed the Parade Game™ concludes that virtual reality experience does not mirror real world experience. Construction in today's real world tends to be large scale and complex. Han contends that because of the sheer size and complexity of most construction projects, small variation result in tremendous deliverable ramifications on the final project outcome. Accordingly, Han, argues that simulated virtual environments provide an affective learning tool if combined with traditional classroom-based learning. It is Han's contention that VR/AR learning systems are not fully capable of demonstrating complexities, dynamics and uncertainties of the construction process especial for large scale projects. The conclusion of this research was that because a vital part of learning requires face to face social and cognitive interaction, a blended learning approach learning system is required. This approach is to ensure the andragogic value of any AR/VR simulation enabler is maximised as an effective efficient learning system.

These and other examples from the literature relating to screen-based simulated technological enablers typify the ability such technological advances have towards providing realistic context rich AR/VR virtual learning systems. The literature is rich with examples of how simulation packages can afford the novice programmer with opportunity to build virtual learning environments. What is not yet researched is how to make these rich AR/VR technological enablers effective for the enhancement of expertise, higher level problem solving cognitive growth.

2.4.3 Remote communication and collaboration technologies

Human to human communication and collaboration is at its most effective when there is warm body contact, more commonly referred to as face to face interaction. Humans use a variety of technics ranging from voice to physical motioning, when communicating with each other [71]. Collaboration technologies for human to human learning who are physically separated (distant learning) try to replicate warm body contact with technological enablers. Jonassen et alias argued that the main collaboration technologies for remote learning exist as (i) computer mediated communication technologies, (ii) computer supported collaborative work, (iii) cased based learning environments and (iv) computer based cognitive tools [72].

Computer mediated communication technologies include email/electronic discussion forums, video conferencing and access to online data bases [72]. The influence of these forms of communication and collaborative technologies is their ability to enable and support discussion, conversation and collaboration. As learning and teaching tools, they are very effective in supporting a learner centred approach. This is because they tend to re-distribute control of knowledge dissemination from one dominant source (educator/teacher) towards the broader learning community [73]. Computer supported collaborative systems (Google hangouts™) supports learning activities by combining technology based communication means with computer technological enablers [74]. This support is provided in the form of software tools which give the learners the ability to edit documents via shared editor systems, converse via video conference and utilise project management tools across a distributed network [75]. The implication of such technology has re-defined the meaning of real world context especially when VR/AR perceptible experiences are included [76].

Case based learning environments is a practical means to apply situated learning theories. These environments aim to provide 'rich contextualised problem solving activities' for single or group learning involvement [72]. The case based learning environments provide learners with real world multifaceted complications (in the form of learning scenarios) which requires the learner to resolve by means of self-motivated independent research and problem solving skills [77]. The learning scenarios are designed to mirror problems that occur outside of the classroom environment. Such an approach is considered as superior in methodology from the linear designed class room based non contextualised problem based learning and role play type activities [78].

Computer based cognitive tools encourage and direct a learners thinking process [79]. Salmon et al contend that learning with technology requires a learner to have a mind-set that considers the technological based cognitive tool as an intellectual partner. This requires them to have a sufficient level of digital knowledge to be able to contextually choose the appropriate technological based cognitive tools as appose to allowing the technology to solely manage the learning process [80].

2.4.4 Gamification technologies

The accepted definition for gamification is 'the application of game-design elements and game principles in non-game context' [81]. The expression was coined in 2002 by a computer programmer [82] and promoted by digital media industry as a marketable feature of their products from around 2008 onwards [83]. The concept behind introducing gamification to technology is for the purpose of motivating and engaging people. The fundamental idea is that gamification can tap into people's innate yearnings for learning, competing, mastering and socialising [84]. McGonigal argued that everything which incorporates digital socialisation has gamification principles as a key element to the design [4]. For example; the most popular social media sites employ game principles within their platform design when they provide mechanisms which instantly rewards user interaction. Tags such as 'like' or option such as 'retweet' are counted (scored) and the higher the individual scores (number of hits/friends/likes/followers/retweets) the more motivated the original sender is to continue engagement. Bogost saw this as commercial manipulation and has suggested the term 'gamification' be replaced with the term 'exploitation-ware' [85].

Mobile or tablet web-based technology has primarily fostered and promoted gamification technology design [86]. Gamification technology can be classed as those web-based systems such as (i) online gaming, (ii) virtual worlds, (iii) online shopping, (iv) online learning/education, (v) social networking and (vi) music repositories, which incorporate gamification design principles [86]. The rapid development of such technology is having a direct impact on all forms of education. It is also evidenced by the fact that a conceptual framework called Technological Pedagogical Content Knowledge (TPACK) was devised [88]. The concept of TPACK was introduced by Mishra and Koehler in 2006 to illustrate the connection three bodies of gamification knowledge (content, pedagogy and technology) have [87]. Figure 2.3 illustrates the framework design which highlights the complexity involved in developing an educational framework that can enable the application of gamification technologies for learning and teaching.

Some researchers have concerns that the mass production of gamification technologies that rely on simplistic reward approach has led to the fun element being removed and gives the user a synthetic appreciation [89]. In fact researchers and developers have begun to de-construct the term gamification based on the notion that gamification is the reward system in place outside of actual gameplay, while 'gameful design' is when the 'playful' actions are the reward [90]. In summary gamification technology is seen as a design which uses elements of game principles and are divergent from entertainment and or serious games, as these incorporate the principles of 'playful design' (gameful play) [91].

2.4.5 Knowledge warehousing and retrieval technologies

Since the mid-1980s data warehouses have been developed and deployed as an integral part of a modern decision support environments, but has not been utilized extensively in education support systems. The basic purpose of a data warehouse is to empower the knowledge workers with information that allows them to make decisions based on a solid foundation of facts [158]. A data warehouse provides an infrastructure that can enable learners to extract, cleanse, and store large amount of personalized content and procedural data for efficient and accurate responses to learner queries. Other implementations are knowledge warehouses, which not only facilitate the capturing and coding of knowledge, but also enhance the retrieval and sharing of knowledge. Knowledge warehousing and retrieval technologies incorporate many fields of research such as (i) data mining, (ii) information retrieval (iii) pattern recognition, (iv) predictive analytics, (v) semantic web, (vi) data warehousing, (vii) web personalisation and (viii) adaptive websites [92]. As discussed by Yacci, there is little knowledge reuse currently across training, documentation, and performance support. In other words, knowledge-based materials developed for one purpose are not shared or reused in others. The possibility of this however is an obvious expectation for future educational systems [159].

Information retrieval is the technology of finding pieces of information and documents of an unstructured nature (usually text) that satisfies an information need from within large collections (usually stored on computers). An information retrieval system is therefore defined here as any device which aids access to documents specified by subject, and the operations associated with it. One of the major stimulants of the development of digital retrieval technologies is the evolution of the World Wide Web. This new information paradigm for handling, storage and retrieval of knowledge is referred to as web intelligence. The development of public-use search engines (such as Google, Yahoo, Bing, AltaVista, Northern Light, Infoseek and FastSearch has resulted in semantically sensitive search algorithms, innovative ranking algorithm, and a better serving of academic and business requirements. The web technologies has revolutionised the way how knowledge for learning is gathered, stored, processed, presented, shared and used [93]. Baeza-Yates Ribeiro-Neto discussed the fundamentals and principles of modern information retrieval [160]. Meisalo et alias observed that despite of the apparent need and efforts for information retrieval in education, the terms

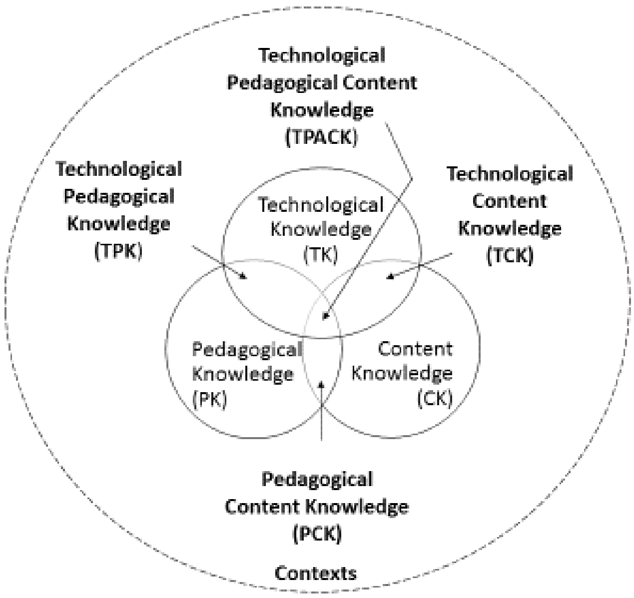

Figure 2.3: Technological Pedagogical Content Knowledge (TPACK) framework [88]

utilised have been quite unclear and vaguely defined [162]. Vinciarelli and Odobez discussed the use of information retrieval technologies to sorting and recognizing presentation slides [161]. The research of Wen et alias addressed sophisticated information retrieval, that is, question-answering mechanisms, and aimed at solutions to produce more efficient and relevant answers particularly in an educational setting [163].

2.4.6 Mobile and ubiquitous technologies

Recent evidence suggests that mobile hardware continue to be the preferred choice of device for distant learning design [94]. There is a growing body of literature that recognises the increase in the technological capacity of mobile phones such as (i) increased screen size, (ii) increased memory storage, (iii) increased multimedia capabilities and (iv) more refined methods of inputting data [73]. What is not clear is the impact mobile phone ownership has on educational usability. These devices were not originally designed for educational applications, ownership among adult learners does not guarantee user familiarity. Also the rate of which mobile phones are updated and changed by owners may be a contributory factor to some usability issues when applied to educational use [95]. With regards to the history of mobile technology applications in education, the literature suggests that there still remains a reluctance to make generalisations about mobile learning requirements [73].

Nielsen and Tahir has considered what these requirements are in relation to interface and usability [96]. Their research suggests that the general mobile technological device usability for educational applications are equal to the standards applied to e-learning but that there are additional considerations such as regular and consistent updating of learning content and a focused emphasis on task driven leaner centred activities [75]. The learner centred approaches in themselves are varied and can be as simple as accessing a forum to communicate peer to peer or educator to learner [97]. The complexity is with the learning process. Analysis of task driven mobile learning is not producing clear definitions for generic requirements of learners who typically use mobile learning devices for education [98]. It has previously been observed that by combining technical usability criteria with andragogic usability components one can go beyond the limitations of metric based definitions for generic mobile learning requirements [99]. In fact when evaluating mobile learning usability in the context of learning and teaching, the concept of andragogic usability helps introduce a design framework that places an emphasis on the close relationship that exists between usability and pedagogy [100].

Extensive research analysis has shown that mobile learning does make a useful contribution to supporting learner development and maintaining learner interest [101]. Mobile learning is fundamental to the development of anywhere, anytime personalised learning [80]. The increased sophistication of mobile technology and specifically mobile phones, means that that a learner today is 3 times more likely to own and operate one in place of a laptop or desk top personal computer [102]. Recent evidence suggests that mobile learning helps improve literacy and numeracy skills brought about by the fact that the device gives the learner confidence to recognise their existing abilities [80]. It has been previously observed that cognitive architecture and the manner in which a person's mind processes multimedia provides an educator with some understanding of how to design and develop effective mobile dis-located personalised learning environments [103].

The concept of personal learning environments is still at its infancy stage [104]. Mobile devices, specifically smart devices have provided the opportunity to develop personalised working and learning environments [105]. As already stated ownership of smart devices is on the increase and have been steadily growing since 2012, in fact the latest statistics show that 48% of devices using search engines to find information are mobile smart devices [106]. The emergence of mobile application software has led to classroom initiatives being adopted by higher education institutes such as Purdue University. They use a mobile application 'Hotseat' in their large lecturer theatres. These applications provide learners the opportunity to ask and answer questions or comment on the discussion thread in real time[3]. Other higher education institutes such as Nebraska–Lincoln's College of Education and Human Science use mobile technology and mobile camera (GoPro) devices to make immersive video tutorials[4]. Such is the increase in higher education institutes to adopt mobile learning devices, there are now dedicated websites to assist educators in deciding if specific mobile applications are suited to meet their specific leaning and teaching needs. Mobile learning (m-learning) case studies are providing evidence proving that by integrating these devices and their software applications into teaching practice makes it easier for learners to contextualise and take ownership [107]. More over the devices and their software application exceed environmental limitations and bridge the gap between formal and informal learning [108].

2.4.7 Findings concerning technological aspects

McGreal argues for online open resources to support ubiquitous learning [109]. It is his belief that the VR/AR learning object semantics are not yet compatible with all forms of software because of remaining commercial sensitivities. The latest literature for technology driven learning is highlighting how higher educational institutes for the main still deliver conventional learning [110]. The fact remains that there is an ever increasing use of technology in normal everyday societal instances. This has an impact on how people are learning on an informal basis. Hung et al argue that technology driven learning needs a formal context and learner profile awareness [111]. Jhao and Okamoto introduced the concept coined 'U-learning' [18]. The distinction is that U-learning can adapt the individual's learning path by providing tailor made context data through the VR environment and social interaction with peers [112]. The natural environment for this U-learning approach is within a digital campus, which 'transcend learning situations through an instructional scaffolding approach' [18]. Digital campus has the ability to encourage self-adaptive learning [20]. Our blended enabler design is a first step towards the long experimental road to perfect the authoring of educational content in a manner that will make it as stimulating as the content of current and future commercially available simulation video games [113].

2.4.8 Learning objects technologies

The recent introduction of open source learning objects (LOs) in the construction engineering industry is being exploited for its unique ability to visually communicate the various stages of real world construction projects [114]. Similar to object orientated programming, learning object (LO) systems exist as elements or entities in digital format and can be reused as content in web-based distant learning environments. The main computing elements are metadata standards and system specifications such as levels of scale, level of detail of data and cross platform interoperability. The types of digital resource that are reused to support learning

[3] https://www.itap.purdue.edu/learning/tools/hotseat.html [accessed June 2017]
[4] http://cehs.unl.edu/cehs/news/engaging-students-mobiletechnology/ [accessed June 2017]

include (i) images or photos, (ii) live data feeds, (iii) live or pre-recorded video or audio snippets, (iv) text, animations and (v) web-delivered applications such as (vi) a java applet, (vii) a blog, or (viii) a web page combining text, images and other media [111]. LO's as knowledge based objects are self-contained, reusable and described by their meta-tags which include their history, meaning, quality and destination. LO elements are units which make up the content and the object and are singular or a combination of elements. Interactivity allows the LO by the action of a user to refer to other internal or external elements.

Buzzetto-More and Pinhey claimed that well developed learning objects should be pedagogically sound, well presented, thoughtfully managed and supported, usable, and reusable. Their research was orientated to the establishment of guidelines and a method for evaluating e-learning quality by providing a model that can be adapted and adopted by interested institutions. In order to ensure that learning objects that support fully online instruction are well developed, a set of standards has been developed [117]. De Waard et alias emphasized that the MOOC concept is now mature enough to be optimised for the challenges of global learners, teachers, and researchers. The recently launched EU initiative of Opening up Education for all stimulates creating MOOC portals contributes to building a roadmap to transform existing MOOC so that vulnerable groups can benefit from them on equal terms [115]. In another paper, de Waard et al. argued that looking at the shift in learning which is happening as a result of the rise in social media, ubiquitous cloud computing, and new technologies, a MOOC complements all these changes, and mLearning offers the devices and characteristics to realize them. As a concrete professional contribution they presented their solution for embedding MobiMOOC and MOOCs in a framework of chaos theory, complexity, and emergence [116].

2.5 Findings concerning aspects of learning environments

2.5.1 Software integrated learning environments

Higher level institutions are rolling out plans to re-arrange the physical teaching environment in favour of learning environments that promote active learning through the use of multiple device connectivity [106]. They are employing digital strategies to optimise the way in which the devices and software are utilised to ensure they enrich teaching and learning. The majority of these institutes have adopted learning management system (LMS) in some form or other. LMS have often been referred to as virtual learning environments (VLE) and essentially they are software designed to enable distribution and delivery of programmes online, tracking learner participation and reporting of learner assessment and progress [118]. There are now several LMS brand names offering software integrated learning environments and generally deployed by the higher level institutes.

The MOOC evolution has resulted in an increased number of higher level institutions adopting one of the LMS brands to digitally distribute learning materials and encourage more student centred interactions. LMS and other such software platforms are now been treated as digital learning environments [119]. The focus is about how the software can enhance the learner and the learning experience [120]. The supply of educational material from commercial entities (textbooks) is shifting from selling text, to offering software resources and services related to the educational content [121]. The increase in availability and ease of access to open source educational material has added to the decline in programme textbook sales[5] and the increase in software integrated learning environments.

2.5.2 Immersive learning environments

Immersive learning environments refers to the development of more flexible learning spaces. These learning spaces (i) support personalisation, (ii) use open source software and (iii) provide formative assessment [122]. Included in this is the number of objects with computer processors and imbedded sensors to permit the transmission of information across networked systems (internet of things) [123]. The emerging trend of technology wearables such as Apple watches™ and Fitbits™ has revealed the potential for converting learning spaces into naturally connected immersive learning spaces. Immersive learning environments use 3D simulation virtual environments to bring learners into the virtual learning space and motivate them to remain active learners. [124]. The steady release of light weight wearable devices coupled with VR/AR software updates has seen headsets develop from the Oculus Rift helmet type design to the Google Glass optical head set. The more of these devices that become everyday wearable items (such as smart phones in western society) will require the higher level institutes to adapt their hardware infrastructure to meet the demand of a digital campus in the truest sense (multiple smart devices connect to the campus network communicating machine to machine, human to machine and machine to human). Tomorrow's immersive learning environment is very different to today's current isolated offerings.

2.5.3 Smart learning environments

Machine learning is a form of artificial intelligence (cognitive computing) giving computer processors the ability to learn without the need for it to be specifically programmed [125]. Machine learning has been instrumental in assisting second generation learning management systems promote adaptive learning. Smart learning environments use all or some of these available technologies (LMS, adaptive, & mobile) to employ communication and sensing technologies (wireless and networked) to empower learners to interact with virtual and real world learning objects. Hwang et al refer to this as context aware ubiquitous learning [126]. Context aware ubiquitous learning is set to offer effective and efficient deep learning but it is in its current format, not without its inadequacies when applied to a smart learning environment.

The notion of a smart learning system is often considered as a technology enhanced learning system that uses intelligent tutoring and adaptive learning software to meet and provide the pervasive personalised needs of the learners [127]. The considered criteria for a smart learning environment is said to be one that is (i) context aware of the learner situation, the real world location of the learner and therefore able to learn which appropriate support is required (learner either online or offline), (ii) able to adapt support based on analysis of the immediate needs of the learner (again both online or offline) and (iii) adapt the user interface (natural, tactile) to meet with the personal factors of the learner at any given period of interaction [128]. The future of smart learning will consist of knowledge being disseminated to the learner appropriate to

[5] Carey, K. (2012). Never pay sticker price for a textbook again. (Retrieved from Slate. com. July, 20, 2013)

their activity (work or play).

2.5.4 Forms of blended learning

As learners and educators have been improving their digital literacy, there has been an increase in online digital activities for learning. At the same time, there is no doubt that various forms of traditional instruction also have merits and offer benefits. This implied the need for mixing traditional and digital forms of education according to various application contexts. When traditional face to face (F2F) learning gradually incorporates any form of digital technological enablers to facilitate learning, it is regarded as blended learning [129]. Blended learning is known as a formal education program in which students learn at least in part through online delivery of contents and instructions with some element of student control over time, place, path, and/or pace and at least in part at a supervised brick-and-mortar location away from home. Nevertheless, there are different interpretations and vocabularies, which hinder a rapid and smooth creation of a common language to enable further discussions. In general, the most common types of blended learning designs encompass additional (to F2F) learning instruction facilitated by means of adaptive learning, mobile learning, flipped classrooms or open source educational material, and learner assessment feedback via a LMS [130].

Implementation models of blended learning are still emerging in an attempt to keep pace with new innovations while some of the earlier models are gradually becoming obsolete. Osguthorpe and Graham overviewed the background of and have defined blended learning as a means that combines face-to-face with distance delivery systems. Accordingly, they have affirmed that various forms of blended leaming environments try to achieve the bests of both face-to-face and online methods - using the web for what can be blended [165]. They also discussed the various goals of creating blended learning environments (such as pedagogical richness, access to knowledge, social interaction, personal agency, cost effectiveness, and ease of revision. Based on a recent literature study, Boelens et alias identified four key challenges to the design of blended learning, namely: (i) incorporating flexibility, (ii) stimulating interaction, (iii) facilitating students' learning processes, and (iv) fostering an affective learning climate. [166].

Staker and Horn proposed a taxonomy of blended learning that is shown in Figure 2.4 [164]. They differentiated (i) informal online learning, and (ii) full-time online learning. In the framework of informal online learning a student uses technology to learn outside of a structured

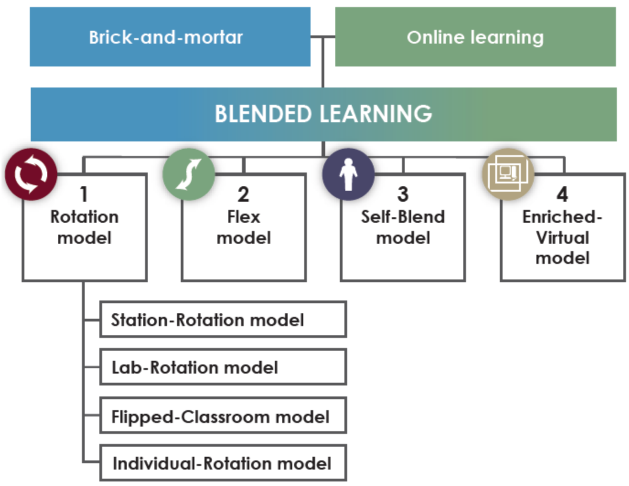

Figure 2.4: Taxonomy of blended-learning (according to [164])

education program any time. For example, students could play educational video games or watch online lectures on their own outside of any recognized school program. In the case of full-time online learning a structured education program is available for the students in which content and instruction are delivered over the Internet and the students do not attend a supervised brick-and-mortar location away from home, except on a very limited basis in some cases, such as for proctored exams, wet labs, or social events. Margulieux et alias contrasted the approaches of hybrid, blended, flipped, and inverted classroom learning and examined existing definitions of these new types of courses [167]. They identified four primary dimensions for these course organization patterns: (i) instructional location describes whether the learner receives instruction in a classroom or in a non-traditional setting (e.g., home, library, coffee shop), (ii) delivery medium describes whether a person or technology delivers instruction to the learner, (iii) instruction type describes whether the learner is receiving content (e.g., lecture) or applying content to learning activities (e.g., practice problems), and (iv) synchronicity describes whether learners are following a group pace or individual pace.

2.6 Discussion and reflections

2.6.1 Major innovations in digital learning

There is a requirement for higher education institutes to become centres of innovation [131]. It entails the need for new approaches to learning and requires new means by which knowledge can be disseminated more inclusively and competencies can be acquired more progressively. The expectation of learners is either get a prospective job on the labour market or become more employable after they graduate. Technology has been immersed in all forms in practically all of the industrial sectors and digital literacy has been seen as a key skill for CEE learners. Since expectations are ever growing, higher education institutes must deliver deeper learning and incorporate skill based training if they are to meet the expectations of their learners and the needs of the industries they serve [132]. The literature provides examples of how technology is impacting on everything that the human does and sees in the 21st century. However, it should be seen that there is a clear divide between total immersion in the technological world and holding onto the traditional means at this current juncture.

Digital learning systems introduced many new educational resources. One of them is learning objects (LOs), which have become a core element in web-based learning systems. The cognitive and perceptive learning elements are equally important and must be acknowledged in design and delivery of LOs. It is therefore a case of deciding what type/combination of digital resources is used and to what level of detail and scale to aim at in correspondence with the (i) pace of learning, (ii) prior knowledge acquired, and (iii) other personal criteria of the participants. A generic approach of designing LOs is to include cognitive and learning aspects so as to divide them into their main elements. These are (i) the conceptual structure of the area of learning, (ii) the aptitudes of the learners, and (iii) the appropriate delivery and assessment sub-systems [139]. The strives after social interaction (described as instructional discourse in certain types of learning outcomes) is important since it improves the participation of the learners.

Standard taxonomy/classification schemes have been developed, which make learning objects more available, easily retrievable, sharable and held in learning object repositories (LOR). An example of this was presented in a report on LOR for a Pan-Canadian Approach. The key areas identified were: (i) the development of interoperability standards, and (ii) metadata schemes of centralised repositories in addition to federated repository networks. It was proposed that the users in a network should be encouraged to play a role in the development and utilisation of learning objects and LORs, from individual input to large-scale digital repositories [133] [134]. The repository should allow for resources to be stored in distributed databases and accessed and downloaded from there for adaptation or use. There should be one centrally maintained index of resources and this needs to be regularly updated and include a full history of the use of the repository along with users' feedback and comments [135]. LOR as an information system requires a development methodology as well as a framework to structure, plan, and develop it through the iterative and continuous cycle of design, implementation, and evaluation [136].

Toward a standardised design of LORs, the following steps should be taken into account: (i) consider the whole web-based learning system that LORs are part of, (ii) locate the main standardisation bodies and their recommendations, and (iii) specifications should cover all possible needs of a Web-learning systems and LOR [138]. As a best of practice design approach of LORs, learning contents should be arranged in a way that supports the interactions among learners and instructors [140]. In a case study done by the Open University (OU) in the UK, which concerned the application of LOs in an open study programme, an environment was established whereby the learner could engage experientially with LOs. A student-directed learning environment was embodied, which supported exposition, interaction, engagement, and feedback, containing all of the important components of a deep learning experience in the design of LOs [141].

The OU's approach appears to adopt constructivism as an educational philosophy and it was also applied in LO design. The fundamental assumption is that learning is an active process of building skills and competence, rather than just acquiring knowledge and instruction. It is a process of supporting the effective construction of knowledge, rather than just communicating knowledge. As a result of these, learners actively participate in the learning process. The goal of learner inclusion and participation has become a design fundamental for LO-based systems. It goes together with the implementation of the principles of generative learning environments. By creating a classification of LO types, LO systems should provide an arrangement for instructional education, as well as positive learning experiences with flexibility, accessibility and adaptability. This should be supported by the entire contents of a networking-based Learning Object Repository [142]. According to Beshears, the quality of LOs and the other educational resource materials has an impact on their continuous use over a longer time period [143]. In addition, it is also argued that the learning material contents and LOs for web-based educational applications need to be adaptable to a potentially diverse communities of learners if they are to show any form of sustainable longevity [144]. As explained later, we considered the contents of existing LORs to assist educators in providing and realizing their learning contents by using the concept of learning objects.

Service oriented architecture framework (SOAF) a system for the semantic indexing of the learning objects in a repository combines automatic techniques for information retrieval with the assistance of tags assigned by the users in a learning community leading to a better up-cycling of these resources [137]. Instructional design educational frameworks conventionally concentrate on content possibilities and content sequencing [84]. The assumption is that this design enables the learners to engage with content 'in a predictable manner' [84]. On the other hand, research literature that links engagement and motivation to effective learning has led us, as will be discussed in the next Chapter of the thesis, to explore various opportunities of blending of technological, cognitive and social enablers in a distant learning and teaching framework design, with the objective of enhancing the stimulation of cognitive growth in the field of CEE. The ideation of an enablers-centred approach, which gave the floor to our research hypotheses for RC2, a conceptual system design will be implemented, which reflects our main findings, namely, that the design of a competitive online learning environment must include: (i) cognitive enablers (perceptive/psychological), (ii) technological enablers (hardware/software), and (iii) social enablers (human interactions and reactions).

2.6.2 The challenge of combining enablers

Our guiding research questions has been formulated so as: '*What are the main architectural and functional features of a web-based learning platform that implements a blended enablers-based system design to deliver support for distant vocational learning/training with the objective of achieving similar or better results than that possible in the case of traditional classroom/laboratory learning practice*?' In this context, the main function of the enablers is (ii) to motivate learners, (ii) to provide perceived usefulness, and (iii) to ensure rich knowledge transfer. The integration of technological, cognitive and social enablers seems to be a straightforward idea, almost a natural phenomenon. The cognitive enablers are both part of, and equally spans across the two other enablers, in the form of cognitive knowledge and skills absorption. The concept of an interactive computer generated simulation (CGS) of real life artefacts and processes can be based on blending a set of mutually interacting and strengthening technological, cognitive and social enablers. Obviously the level and the format of blending of these enablers may vary since it is dependent on the application domain and context, but also on the targeted perception of the learners and psychological state of their mind.

However, from the perspective of implementation of a blended enablers-based system design, the literature cast light on many challenges. One of them is the lack of a comprehensive underpinning theory. Actually, the current literature does not offer a complete theory or some combinable theories that would explain how to blend the above-discussed enablers in different contexts. As a consequence of this, there is no template implementations of similar systems that we could learn from. Another issue is the different genres of the above three enablers. The technological enablers are tangible and identifiable as system components, whereas the social and cognitive enablers are somewhat more intangible. They even appear as a set of abstract enablers. In order to determine how, for instance, perceptual and psychological immersion can be evaluated, thinking in various learning scenarios seems to be necessary.

We have learnt from the completed literature study that supporting features such as incorporating mobile devices in problem solving and working according to collaborative learning scenarios improves the effectiveness of learning [145]. It is also discussed how societal use of technology influences the traditional education approach to become more independent learning processes [146]. Other influential factors are (i) implementation and inclusion of relevant task- and role-based scenarios, (ii) development of relevant digital content materials, and establishment of a community-based learning practice - especially in the area of learning procedural skills [147] [148]. Various publications emphasize the need to ensure that the learning and teaching environment is flexible when accessed by distant learners [149]. However, flexibility does not only relate to access to materials and contents, but also to open access to a 'network' of learning objects [150].

Nevertheless, combination of the abovementioned three different enablers is a challenge not only from a methodological and a pedagogical point of view, but also from information technological/engineering and system integration points of view. Their combination in one single system assumes a software-integrated system architecture with a very large number of usability and utility features. The review of the literature has identified some sort of scientific knowledge gap in this respect. For instance, it does not explain what supporting features are needed for the successful introduction of blended enablers into a design framework for a remotely interactive and largely immersive distant learning environment for CEE? Furthermore, what the most influencing ones of these enabler features are (that must be explored and considered at conceptualising the architecture and designing a web-based stimulating learning systems for CEE)? To answer these and similar questions needs exploratory research, which will actually be in focus of research cycle 2.

2.6.3 Open issues and further research opportunities

Our aspiration is to build a generated web-based 3D virtual simulation of a refrigeration engineering training laboratory. This idea projects ahead a refined 3D VR learning application, which incorporates a complex 'people-centred approach' to a learner controlled learning and teaching environment for dis-located learners [169] [151]. Ideally it includes multiple unpredictable 'use events', which will both engage the students' cognitively and affectively, while enhancing their problem-solving skills within the discipline of refrigeration engineering. A 'people-centred approach', or in our case, a learner-centred approach, requires the system design to provide supports that ensure our learners can take control of their learning environment [152].

To achieve this vision our objective was set to develop a design framework of blended technological, cognitive and social enablers that could contribute to successful development of an effective web-based stimulated learning system (WBS-LS) for distributed construction engineering education. This was pursued to enhance real life personalised learning experience in the discipline of construction engineering. It was expected that many open issues will be resolved in the process of system conceptualization and development, but many new issues also popped up. Many of the emerged issues concerned how VR/AR-based computer generated contents simulation technologies can be applied in the most effective and efficient manner. In line with the outcomes of the literature review, we also deem further research important in areas such as: (i) the early design part of stimulated learning in virtual environments, in which anagogical support plays an important part. (ii) The need to investigate design principles that will lessen the complication and time constraints to develop VR/AR stimulated environments. (iii) The issue of learning experience when different virtual reality technologies are used in practice.

2.7 Some conclusions

This Chapter provided an overview of the current state of the art by considering the most pertinent publications in the literature. Obviously it could not exhaustive in this context. The reasoning model positioned human factors and diversity issues as a central part of the investigation. The research shed new light on how CEE practitioners have started to take notice of these important phenomena and strived after embracing technologies for the purpose of improving learning experience and meeting the construction industry expectations. The review of the literature has identified a scientific knowledge gap and considered this as the primary focus for the conducted research. The lack of knowledge is actually broad - it is associated, for instance, with sensory interfaces, measures of effectiveness, importance of the sensation of presence, and cyber sickness, etc., which are already subjects of on-going investigations across many disciplines outside of the construction industry.

The finding of the literature study enabled us to formulate the following conclusions:

- There is a need to consider how VR stimulated learning can contribute to the holistic ecology of education.
- Though there are many consolidated learning theories and methodological approaches, they are not sufficiently specific to construction engineering education.
- Though regarded as important aspect of organization and management of education, diversity issues has been considered only superficially in technology driven education and advanced technology based learning environments.
- It has been found important to pay attention to human experiences in various context and to be simulative to motivation and engagement of learners.
- Well-designed user interfaces should provide informative feedback, permit easy reversal of actions, support an internal locus of control, reduce working memory load, and provide alternative interfaces for novice and expert users.
- Many publications underlie that current advancement of technological enablers provides many opportunities to incorporate social aspects in the development of web-based online learning systems, which in turn, as disclosed above, offer further opportunities for socialization in learning.
- Based on a proper consideration, the necessity of socialization can be recognized in the practice of current collective, remote, and peer assisted learning. However these should also feature web-hosted distributed learning environments.
- Though the use of VR/AR screen-based technology in CEE has already begun, more sophisticated and comprehensive embedding is deemed to be necessary in order to achieve the highest possible impacts on learners and professional construction practitioners.
- The literature has proven that the introduction of screen-based technology enabled learning systems to CEE can have a positive and practical influence, provided a relevant set of social and cognitive enablers are considered.
- The literature highlighted the need for further research into how much added value simulated learning VR/AR applications could provide for a distant but immersive online education, having in mind that the rapid growth of screen-based VR/AR technology has become more cost effective and available to a greater majority.
- Andragogic theories and support means need to be combined with stimulated learning in virtual environments in order to improve both the experience and the expertise of learners.
- It has remained an open issue how stimulated learning in virtual environments can be integrated into the daily practice of CEE effectively and without disproportional efforts.

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Chapter 3

Research cycle 2: Influential factors and causalities

3.1. Introduction

3.1.1 Objective of knowledge aggregation

The factors influencing higher education can be identified from analysis of the reported trends and challenges that are considered by educational peers as important, mainly because of the impact they have or could potentially have on learning and teaching in higher education [1]. At the heart of any educational system is the supports put in place to ensure the human learner achieves the desired learning outcomes. Cognitive theories have resulted from investigations about what influences the mental concepts of the individual or the collective as human learners [2]. Higher education institutes design their services and supports based on cognitive learning theories. Their objective is to ensure the learner experience meets the learner's expectations. Modern day living is exposing humans to a labyrinth of experiences which affect how individuals react to technology and to social interactions [3]. It is these experiences that are influencing the pedagogic, andragogic and didactic learning materials and supports being offered by higher education. The explorative part of this research cycle is to gather more knowledge about how these combined factors can and do influence the type and level of learning support extended by higher level institutes.

3.1.2 Introducing the applied reasoning model

Figure 3.1 is an applied reasoning model which captures the factors that were influencing the types of services and supports encompassed at higher level education when we began this research. Accordingly the influential factors were (i) technological, (ii) andragogy/didactics, (iii) personal learning and (iv) social learning. It is recognised that as the cost of technology to the consumer begins to decrease the use of that technology can begin to increase. An obvious example is the mobile phone and its latest iterations (smartphones). Equally it is also accepted that more people are entering (for the first time or re-engaging with) higher education. These trends for higher education and lifelong learning combined with an increase in technology interaction by consumers, has resulted in educators having to re-consider the pedagogy, andragogy and didactic supports. The primary focus for a review of the supports and services is to consider if what is currently in place meets the needs of the increased numbers and the varied demographic type of learners. These new learners come with highly varied personal experiences, multiple intelligences/learning styles and varied levels of digital literacy.

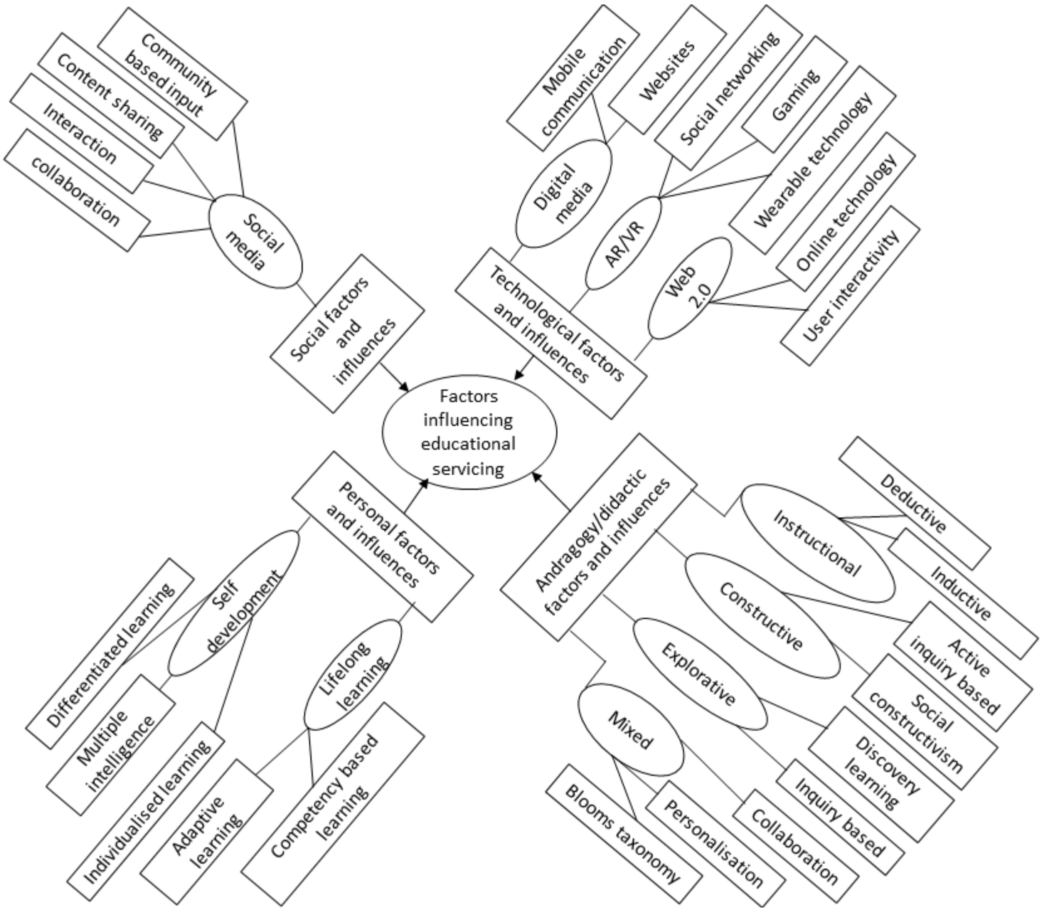

Figure 3.1: Major factors influencing knowledge dissemination

3.1.3 The research approach

The approach applied in RC2 included a desktop survey to identify and review the literature relating to each of the influential factors. The literature relating to andragogy defines it as the social science applied to help adults to learn. It places value on the use of a learner centred teaching and learning approach and has given rise to the student centred learning and teaching trends [4]. From this starting point we then looked directly at the relationships each of the other factors have with higher education and each other. For example the more mature a learner is, his/her learning motivation becomes internal and personalised. This led us to consider how the introduction of technology and socialised learning effected the learner's overall satisfaction with his/her higher education experience. Once we aggregated the knowledge we analysed the data and cross referenced it with CEE learning and teaching practice. Data analysis was employed with the objective to identify new reasoning design specification, and to generate new strategies and principles for the building of a web-based construction engineering education (CEE) framework.

3.1.4 Challenges of doing this study

For the most part the key factors as identified in Figure 3.1 have an extremely wide spectrum. This made it all the more difficult to isolate the influential factors since they typically appear in vast quantities in a number of literature studies. In some cases less significant factors to the science of learning and teaching as applied to higher education receive larger emphasis thereby making it more difficult to determine what the most influential factors were. Consequently the main challenge was the conformity part of this research cycle because, without confirmatory actions the aggregated knowledge could not be accepted as consolidated.

3.2 Andragogic and didactic factors and influences

1.2.1 Instructive approach of education

There are a number of cognitive studies which have conclusively proven that a learner will learn more if they see the material as being important to them and they can engage actively with the learning [5]. At this point it is important to note that there are differences between andragogy and pedagogy. A direct definition of pedagogy is 'the art and science of educating children' [6]. Pedagogy is educator centred teaching, where all decisions relating to what, when and how learning takes place are made directly by the educator. Andragogy on the other hand is about understanding how learners (adult learners/higher education) approach learning. One learner's reasons for learning are different than another's (e.g. lifelong learning in adulthood versus forced learning in childhood) [7]. The characteristics of adult learning are based on assumptions that the learners are (i) independent and self-directed, (ii) have life experiences to provide a resource to build learning on (iii) willing to learn especially in a socialised learning context (iv) adult learners place an emphasis on problem centred learning as appose to subject centred learning and (v) internal motivation to learn is personal [7]. Accordingly learning activities using instructional methods that necessitate learners to apply knowledge in a complex and meaningful way tends to have more effective learning outcomes for the adult learner. Each learning activity utilises the delineated knowledge base that the learners have either been previously exposed to or are about to be introduced to [8].

Behaviourism, cognitivism and constructivism are the three main learning theories behind the application of instructional designed learning and teaching activities [9]. Essentially the role of educator changes to that of facilitator who applies an instructional design model to assist the learners achieve the learning objectives [10]. The design model contains varied instructional methods based on the individual learning styles. For example; (i) instructions reflect the complexity of the learning activities as each learners' knowledge progresses, (ii) the facilitator should provide demonstrations and encourage peer to peer learning via discussion, (iv) in order to build on existing knowledge the instruction should help learners organise and structure new knowledge gain and (v) the instruction facilitates peer critiquing and the fusing of newly acquired knowledge with existing already acquired knowledge [10].

Instructional design must also consider the principles associated with learning in a social-cultural environment and their effect on the selection of educational outcomes. Wagner developed the technique of instructional curriculum mapping to integrate intellectual skills with supporting objectives from different domains while Briggs expanded on prescriptions for media based instructional functions [11]. For CEE, the learning approach tends to place an emphasis on the behaviourism and constructionism learning paradigms. Therefore it is our contention that one of the implications for a web-based CEE support system is that it must prioritise on instruction that builds on learner's experiences in a collaborative way. The use of the cumulative learning theory and a learning hierarchy means that different instructions are required to assist the learners obtain various levels of learning outcomes. The methods most associated with CEE are based on these different approaches to instruction to ensure the dissemination of CEE knowledge is effectively distributed to the learners and that these learners successfully retain this new knowledge. In general the approaches include (i) direct instruction, (ii) peer to peer discussion (iii) experiential learning (iv) problem based learning and (v) simulation based learning.

Instructional strategies to foster cognitive learning include instructions that provide (i) clear information about the aim, purpose and learning outcomes, knowledge needed and performance expected (ii) opportunity for learners to engage actively in the learning and to be provided with the opportunity to reflect on the new knowledge, (iii) timely and concise learner feedback to help ensure effective progress and (iv) motivational activities that are engaging, interesting and build on existing learner knowledge [12].Instructional design has directly or indirectly influenced educators of CEE in higher education [13]. The majority of these subject matter expert educators, have had some involvement in the design and implementation of instructional learning materials but have had no formal training and are not aware of the essential phases of instructional design [13]. Therefor the introduction of technologies to assist instructional design theories can bring about a new set of problems. In fact the rapid pace at which these technologies have been emerging has led to the primary question becoming; 'to what extent does the use of technology impact learning, performance and instruction' [14]. The challenge for higher education is to make the use of technology effective and efficient, this requires their educators to have training in the science of education, in instructional design and to have a high level of digital literacy [15].

The advantages for applying instructional design models into higher education are numerous and include; (i) the focus of the instructions are learner centred and promote learner advocacy, (ii) a well-designed learner instruction model promotes effective and efficient learning and teaching because it eliminates all non-relevant knowledge content and is subject to regular evaluation and revisions, (iii) The process to develop instructional design models requires the higher education teaching body to communicate and co-ordinate the design, production and delivery of instructions [16]. On the other hand the disadvantages to applying instructional design models to higher education are; (i) instruction design models are not the only solution towards effective and efficient delivery of higher education. In particular in cases where the learning aims and objectives cannot be identified in advance or in the case of non-instructional education, (ii) replacing the traditional teaching role can have a demotivation effect on the educators who may view the facilitation of knowledge dissemination as a less efficient method over their direct method of delivery through lecturers and (iii) the time required for facilitating instructional design learning is longer than the time needed for a subject matter expert to impart the knowledge via a teacher centred lecture [16].

3.2.2 Constructive approach of education

The constructivist approach to learning and teaching requires learners to be actively involved in the process of knowledge construction and exploring its meaning [17]. Thorndike based his constructivist theories on four key principles; (i) learning involves repetition and reward, (ii) stimulus and response association are linked when they are part of the same 'action sequence', (iii) learning and knowledge gain is built on the experiences of the individual learners and (iv) intelligence is determined by the amount of associated knowledge content learnt and retained by individuals [18]. The constructivist approach which was first pioneered by Bartlett in 1932 is about creating a learning environment which provides learners with the means to build knowledge from active pursuance of meaning on the bases of personal experience, negotiated meaning, shared perspectives and changes to the internal mental concepts brought about as a result of collaborative learning [19]. Constructivism builds upon cognitivism and behaviourism by virtue of the fact that the principle of personalised view of learning and multiple perspectives are accepted in all three learning and teaching paradigms [18]. In fact the literature suggests that both cognitive approaches and behavioural strategies tend to be an integral part of constructivism instruction [20].

Saettler discussed how constructivism, cognitivism and behaviourism have had an influence on education and in particular how they influenced the way in which technology was introduced and applied to higher education [20]. For example higher education have adopted the use of module descriptors to inform learners what they can expect to learn (purpose, aim, objectives, learning outcomes and assessment). Other examples include (i) behavioural objectives, (ii) the teaching machine phase, (iii) the programmed instruction movement, (iv) the individualised instructional approaches, (v) computer assisted learning and (vi) the system approach to instruction [20].

Advantages of the constructivism approach is that the learner is provided with the knowledge and skills to problem solve real world challenges. This ensures the learner can deal with real life situations more easily. They have more of an opportunity to think about possible solutions to a real world problem which may be unique. Disadvantages of the constructivism approach is that it encourages independent thinking often conflicting, this can be problematic in situations when conventional responses are all that is required.

3.2.3 Exploratory approach of education

Traditional teaching is the practice of the educator (i) presenting the information, (ii) enabling the learner to practice with the new knowledge, (iii) the educator correcting course work and assessments and (iv) providing a grade to indicate the depth of knowledge. The exploratory approach is when the problem instructions are presented to the learners for them to discover a solution and document the rationale. This indirect instruction method is applied to problem based learning, project based learning and inquiry or discovery method learning. The influence of exploratory learning on higher education is the manner in which it assists the learners to develop effective academic research skills. It also prepared learners to become independent thinkers, a valuable employment skill to have in the construction industry.

The advantage to using such an approach is that it helps learners to accept opinions of others and at the same time learn to become self-motivated independent learners. The disadvantage is that more time is needed for learning and that the educator must ensure as the facilitator that the learners don’t head down a wrong path for answers and become frustrated and de-motivated.

3.2.4 Mixed approach of education

A mixed approach instructional model for education supports wide ranging, diverse and blended perspectives of constructivist learning theories. Applying a mixed approach method as a means to propagate knowledge enables the learners to approach the leaning based on what they already know currently and concentrate on what they perceive as new knowledge. With mixed approach models the learner focus tends to be towards content structure, cognitive process and collaborative activities [21].

For web-based learning the instructional model applied to the programme design should enable learners to apply their new knowledge in the workplace and evaluate the results [21]. One such mixed approach instructional model is depicted in Figure 3.2 and was developed by Alonso et al as an instructional model for e-learning with a blended learning approach [21].

The analysis defines the learner characteristics before defining the learning content and environment. The design defines the learning approach and the type of content to be provided. The development is about the learning process in real terms. The implementation is when the web-based platform is built. Execution is when the learner engages with the learning process. Evaluation information is used to monitor learner success and quality of the learning and teaching approach. Review is analysing the results to determine where the learning needs to be refined.

3.3 Technological and system factors and influences

3.3.1 Communication and social networking technologies for Web 2.0

The latest generation of Web 2.0 communication technologies has radically changed the knowledge development and its dissemination. Education plays a major role in knowledge distribution and development and therefore must apply and integrate the available and emerging affordances [22]. It is our impression that learners have more experience in the use of these technologies than is offered within the construction engineering higher education institutes [23]. The reason for this is that young people interactively use new technologies

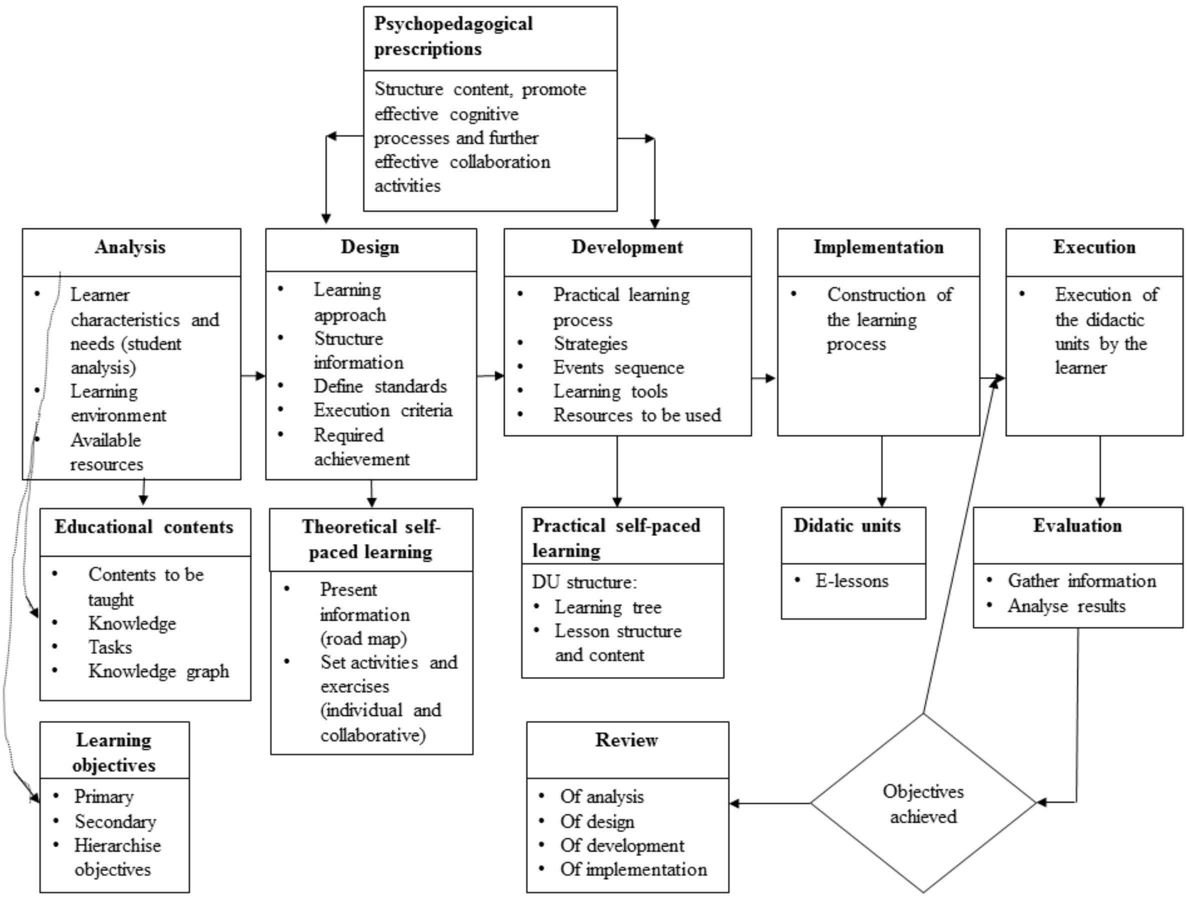

Figure 3.2: Blended e-learning instructional model [21]

outside of education and have developed a digital literacy towards mobile computing.

2013 was witness to a shift in the type of computing devices in use. Smart phones and tablets started to become more powerful with more natural user interface making the traditional desk and lap top based computing less intuitive [1]. The influence of such technology now has learners connected to the internet anywhere they go. As a result the internet has grown useful and relevant knowledge content. In 2013 the mobile market grew to 6.8 billion users with a large majority of these based in developing countries [24]. The unforeseen growth of mobile devices and the software applications that they run has provided higher education institutes with the opportunity to convert the concept of using technology for educational enhancement into the reality [1]. The general consensus among higher education experts was that if mobile devices continue to grow their capability and number of application software then the potential for them to facilitate almost any educational experience' is high [1].

The predicated challenges for higher education institutes in 2013 were questions such as; (i) what is considered as digital literacy and how is it affected by digital media literacy, (ii) how to evaluate social media based research as a new form of peer review approval, (iii) how is mobile technology changing the attitude of the traditional lecturer/researcher from a mental concept of; 'what has always worked', to embracing the change, (iv) how best to use learning analytics to provide personalised learning and instruction, (v) how to make sure the new learning platforms are capable of providing the supports and services needed to enable students engage with the subject on a deeper level and (vi) lack of time due to daily workload has meant quite a large number of academics have yet to use the technologies to teach or organise their own research [25]. As we approach the year 2017 the challenges remain very similar and in some cases the same.

This is in spite of the significant progress in learning, teaching and creative inquiry. For example the Adams et al 2017 NMC horizon report continues to discuss and hypothesis how the current (in 2017) challenges continue to have elements that need to be overcome under the headings of (i) expanding access and convenience; noting the challenges with disparities in digital infrastructure and learner to learner engagement between groups, (ii) spurring innovation; noting the challenges for higher education institutes toward the creation of graduates who have the skill set and problem solving knowledge to redefine the job market through creative and innovative thinking, (iii) fostering authentic learning; noting how activity based learning such as problem based learning and other such models will ensure learners are active contributors to the knowledge banks. It was also noted under this heading that there continues to be challenges in how to deliver on this aspiration because of the traditional classroom space and current teaching/research contracts still in existence at higher level institutes, (iv) tracking and evaluating evidence; to find ways of developing adaptive learning that uses tracked and evaluated learner data to provide personalised learning supports and services, (v) improving teaching profession; lecturer must engage with ongoing professional development to transform from pedagogy teacher focus delivery to andragogy mentor/coaching delivery of knowledge.

The evidence suggests that the higher institutes are still placing little emphases on encouraging or rewarding professional development for staff who need to re-skill from using a teacher centred approach and develop the skill set to delivery via a student centred mentoring and coaching approach and (vi) spreading digital fluency; simply understanding how to use one or multiple devices is not sufficient to meet the standard of digital literacy required in the new world. Learners and educators now need to have the skillset to be able to make connections between the tools and the intended outcome. They are required to apply the technology in a creative and innovative manner and have sufficient knowledge and understanding to be able to adapt from one context to another context [26].

3.3.2 Augmented and virtual reality from an implementation perspective

Virtual reality (VR) digitally recreates a real world scenario using a range of software and hardware platforms, Augmented reality (AR) on the other hand superimposes some of these VR experiences as digital elements in the real world. They are used interchangeably and share some of the same software and hardware technology but the interactive experience is noticeably different. VR offers the user three degrees of freedom, that is it is quarantined in a computer generated world view while AR provides six degrees of freedom in that it uses visual and auditory senses to provide you with sensory information overlaid on the world that you are surrounded in [27].

AR incorporates the use of wearable technology such as smart glasses, in fact it is expected that smart glasses will have a circulation of 1 billion by the year 2020 and that within 10 years of this date they are on target to outsell mobile smart devices such as mobile phones[6]. The research literature is predicting that within a short to medium term time period construction and other service industries could begin to employ the use of augment reality smart glasses to assist human's problem solve or diagnose and repair technical faults[7]. So instead of taking your smart phone out of your pocket to look up information (user manual) your augmented hardware device (smart glasses) will overlay your real world view with information from a digital source to assist you in implementing a correct sequence of events needed to resolve any given problem [27].

VR utilises software and hardware platforms to simulate and digitally re-create numerous and complex behaviours that exist in the real world [28]. Sherman and Craig describe VR as virtual worlds which are constructed in a 3D space using computer graphics. This can be enhanced with the addition of virtual human presence that has an effect of creating the illusion of an immersive experience, (i) interaction, (ii) navigation and (iii) sensory experience provided by the virtual world and its objects [29]. The continuing evolution of VR computer simulation software has generated lower cost, accessible and more intuitive tools. These tools are now used for the development of AR/VR learning environments.

Open Graphics Library (OpenGL) is an application programming interface (API) for rendering 2D and 3D vector graphics and interacts with a graphics processing unit (GPU) creating high resolution rendering. Open GL is the foundation and support for modelling, animation and game engine platforms[8]. There are a number of VR game engine software packages available to develop screen-based simulation. Table 3.1 provides an overview of the most common open GL platforms currently available for developing VR environments.

[6] http://www.augmentedreality.org/smart-glasses-report [accessed June 2017]
[7] http://www.gartner.com/newsroom/id/2618415 [accessed June 2017]

[8] http://openglbook.com/chapter-0-preface-what-is-opengl.html [accessed July 2017]

The nature of game engine software means that they can be scaled for multiplatform systems for different performance capabilities ranging from tablets to sophisticated virtual reality workstations. Working with such large data sets requires intuitive tools for rapid development workflow. It is not uncommon to adapt the same game engine environment, objects and models to create multiple games or to transport them to multiple web-based platforms. A packaged 'game file' is designed to execute as a standalone application, requiring no additional proprietary software installed on the end-users hardware device. In addition, Augmented Reality (AR) and immersive experiences using wearable technology enhance the VR experience whether for entertainment or for education [27].

Virtual reality games are used for both training and providing entertainment. Augmented reality has begun to excel in these areas as the wearable technology begins to become more light weight, streamlined and affordable. The general consensus about VR is that it is a testing ground for AR. Virtual helmets inclusive of simple products such as google card board take the user away from the real world and immerses them in the computer simulated virtual world. AR devices, such as smart phones and smart glasses, give the user the opportunity to view the real world and blend these views with digitally created virtual scenes [27]. On the other hand digital objects which have been firstly constructed in a 3D graphic modelling platform before being exported into a game engine platform can further enhance virtual worlds for 3D visualisation and allow for the possibility of an immersive VR experience especially when user interaction is generated within the game engine platform [30].

Table 3.1: Open source GL platforms

Name of game engine	Description
DX Studio	A 3D game engine with complete tools for 3D video game development. Upgrading to paid licenses unlocks extra features
Game Maker	Uses its own scripting language, GML. A paid upgrade unlocks Direct3D support along with the ability to run native code
NeoAxis Game Engine	Windows and Mac OS X multi-purpose 3D engine with Web deployment. For simulation, visualization, and games. Free for non-commercial projects.
Unity	A game engine not tailored to a specific game style for web, Windows, Mac OS X, Linux and mobile platforms. The free version is feature limited compared to the Pro version. Support for Nintendo Wii, PlayStation 3, and the Xbox 360, and Adobe Flash player is available as add-on licenses.
Unreal Engine 3	UDK — Epic games released a free edition, called UDK (a binary release of the engine), which allows use of the engine for non-commercial games and applications for free. Commercial titles are also allowed under specific terms
Blender	2D/3D game engine packaged in a 3D modeller for quick and intuitive use; fully integrated bullet physics library
Stingray	A 3D game engine distributed by Autodesk for game development, real-time rendering, virtual reality, and design visualization. The added advantage is its direct compatibility with building information modelling software

Intelligent information enhanced models however facilitate the integration of data from different sources, scales and disciplines into a single cohort model [31]. As an example, Stingray is a 3D Autodesk game engine designed to be compatible with building information modelling (BIM) platforms [32]. A BIM object is comprised of intelligence with semantic attributes which represent the elements of a building structure and are organised within a 3D virtual environment [33]. The current reasons for exporting a BIM object into a game engine is for the purpose of packaging BIM data to be used as a simplified and more intuitive communication of project information for a client user [34]. One such case of packaging BIM modelling data for end user application involved a new hospital BIM design packaged as a visualisation communications tool to train staff on how to complete specified procedures in the new hospital layout [30][35].

3.3.3 Using digital media

Digital media technology was not developed for the purpose of education but because it is in use in the everyday lives of the learners it has been seen to help towards developing learning, teaching and creative enquiry. For this reason it has managed to find its way into the spectrum of educational technology. Digital media technology is continuing to evolve at a rapid pace with new ideas emanating from and being introduce to the growing number of societies who have begun or are beginning to use the technology [26]. Using digital media to achieve deep learning is exercising the minds of the policy makers in higher education. Because of the natural way in which today's learners employ digital media their education has been brought about by means of social constructivism. These learners grew up in a digital society with the latest internet technologies referred to as 'Web 2.0'. As a result of Web 2.0 the digital learner does not tend to perceive cyberspace as an instrument or a tool but are more likely to perceive it as reality [36]. Digital media is the new source of knowledge for the digital learner. It is an integral part of the new digital society creating a new objective world as it occurs [31].

As mentioned earlier the pace of technology change has increased expediently, for example the iPad, which was launched in 2010, had sold over 1 million worldwide by 2012, and many other types of hand-held devices now form an integral part of our daily lives and routines [37]. The transmission technology, which connects these devices, has also been increased in both bandwidth and reliability. Web 2.0 has provided a digital infrastructure network that is capable of (i) receiving various types of content from the users and (ii) supporting communication among large volumes of users thereby supporting the formation of virtual communities [31]. Digital learners are now being taught visual coding through initiatives such as CoderDojo[9], which among others uses the Microsoft Scratch software. Digital learners are increasingly being exposed to game engine platforms in their daily lives which simulate real life scenarios [145].

3.4 Personal factors and influences

3.4.1 Self development

Personal self-development takes place over the entire life of an individual. It is not limited to either formal or informal activities but when it is taking place at higher education it is dependent on supports and services. Institutes employ personal development methods to ensure their

[9] Coderdojo Foundation, "Coderdojo, Available online at: https://coderdojo.com. [Accessed 13 January 2017].

programs, assessments, tools and teaching technics are fit for purpose. The supports and services must help leaners to become self-aware, have a sense of direction, improve focus and effectiveness, enhance motivation, help individuals become more resilient and improve social skills. The evidence emerging from recent educational literature provides proof that when learners are given the opportunity to personalise and control learning content, their learning achievements are increased significantly [38].

The question of learning and how people learn best has been at the forefront of educators minds since learning and teaching began [39]. The idea of students taking control, managing and self-regulating their own learning process brings exciting challenges [40]. The result of a positive learning experience can determine improved performance and measure the potential for future learning success [35]. As already mentioned at the beginning of this chapter, established evidence-based student centred and self-regulating learning theories are now recognised as central to the development of learning practice across many fields of education. Because learning is a process that leads to change it is important that educators remain conscious of learning theories and embed them into the design and implementation of the educational framework [41].

3.4.2 Lifelong learning

Lifelong learning is the ongoing pursuit of knowledge either for personal or professional reasons [42]. Often referred to as active citizenship it is linked to the concept of personal development in so far as it is normally about self-preservation, employability and on occasion competiveness [43]. When the term lifelong learning is used the assumption is that learning is not confined to any one place, time or setting. In fact Tough provides evidence that up to 70% of learning is self-planned and self-regulated [44]. Educational technology has increased the opportunities for lifelong learning and enables learners to have global interactions with others and their environment in a minute by minute, daily, weekly or monthly basis [45].

Lifelong learning has played its role in the growth of adaptive learning educational technology. Higher education institutes are using technology as interactive learning and teaching devices. The technology collects and analysis data inputted from lifelong and other learners interaction via their responses to questions, tasks and experience. The institutes then use this information to adapt the pace and level of which it exposes each individual learner to the knowledge content. The aim of adaptive learning is to create the means for personalised learning environments and encourage learners to be active collaborators by constantly exchanging information between the technology and the human regardless of the time place or activity of the human [46]. Bloom et al explain how adaptive learning technology is implemented in several types of educational systems such as (i) intelligent tutoring, (ii) computerised adaptive assessment and (iii) computer based pedagogy/andragogy. To work effectively for each type of system, computer scientists devised modules to house the necessary groups of algorithms. Normally the expert module is the knowledge bank of material which needs to be disseminated. The student module tracks the learner activity and gathers learner data for analytics. The instruction module transmits the information to and from the technological device. The instructional environment module is the human computer interface (HCI) for machine to human interaction [47]. Figure 2.3 illustrates the architecture for an intelligent adaptive learning system [48].

Studies over the past two decades have provided important information about how usability success of these devices as educational technology is determined by measuring the level of improved learning. Nielsen et al suggests that the adaptive learning system that are compatible with mobile technological devices for educational applications are equal to the standards applied to e-learning programmes but, there are additional considerations such as regular and consistent updating of learning content and a focused emphasis on task driven learner centred activities [49]. Analysis of task driven learning using adaptive learning mobile technology is not producing clear definitions for generic requirements of learners [50]. It has however, been previously observed that by combining technical usability criteria with andragogy usability components one can go beyond the limitations of metric based definitions for generic mobile adaptive learning requirements [51]. In fact when evaluating mobile adaptive learning usability in the context of learning and teaching the concept of andragogy usability helps introduce a design framework that places an emphasis on the close relationship that exists between usability and constructivism learning theories [52].

Extensive research analysis has shown that adaptive learning educational mobile technology does make a useful contribution to supporting learner development and maintaining learner interest [53]. The concept of personal learning environments is still at its infancy stage [54]. Adaptive mobile learning technology is fundamental to the development of anywhere, anytime personalised learning [56]. The increased sophistication of mobile technology and specifically mobile smart phones, means that that a learner today is three times more likely to own and operate one in place of a laptop or desk top personal computer [57]. Recent evidence suggests that adaptive educational mobile learning helps improve literacy and numeracy skills brought about by the fact that the device gives the learner confidence to recognise their existing abilities [49]. It has been previously observed that cognitive architecture and the manner in which a person's mind processes multimedia provides an instructive education designer with some understanding of how to design and develop effective mobile dis-located personalised learning environments [58].

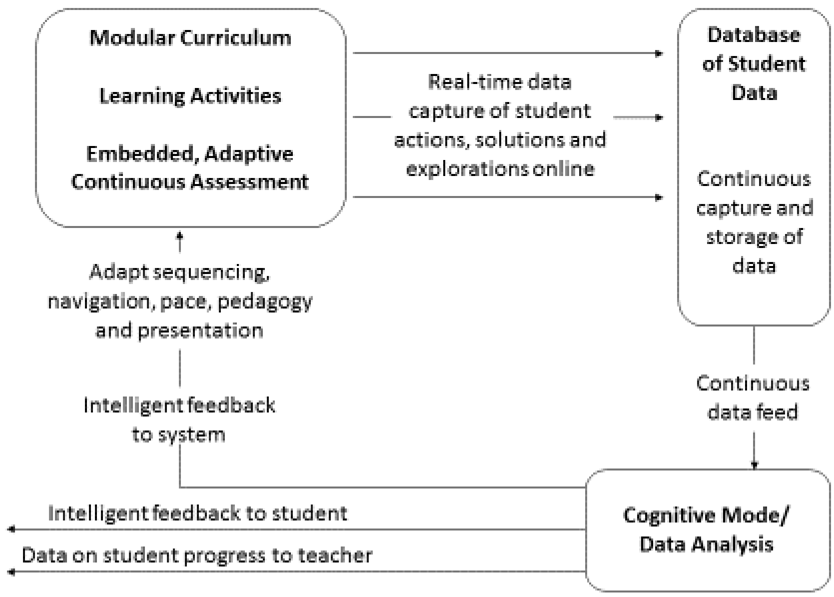

Figure 3.3: Architecture for an intelligent adaptive learning educational system [43]

3.5 Social factors and influences

3.5.1 Use of social media by learners

The term social media tends to refer to computer mediated software technologies that permit the formation and distribution of material about human forms of expression [59]. As with all Web 2.0 software technology the pace at which new iterations are being developed has made it extremely difficult to provide one definitive definition of social media. The features most common to social media software technologies tend to be that (i) they are web-based and interactive, (ii) users generate and uploaded the content for distribution (iii) user creates profiles (personal or business) which are maintained by the commercial social media provider and (iv) social networks are established by connecting with other user profiles [60]. These interactive platforms provide a technological means for (i) person to person, (ii) business to business, (iii) business to person and vice versa and (iv) community outreach contact [61]. The literature provided and continues to show evidence of large percentages (> 80 %) of populations who are subscribed to one or other type of social media account [62]. The evidence suggests that the younger age profile (teenagers) account for over 60% of the population who have social media profiles [61].

3.5.2 Use of social media in education

Considering the large proportion of any given day that digital societies spend online, social media sites seem to occupy the largest majority than any other type of Web 2.0 digital media[10]. The positive influences of social media include improving an individual's sense of connectedness with the world around them. Business and education see it as an effective tool for communication and in some cases for data mining (consumer habits, learner activity). The negative or disadvantages to social media tend to be metal health issues such as depression, bullying and harassment[11]. There are numerous other disadvantages inclusive of security and fraud type issues but in spite of all this social media continues to grow in popularity year on year.

Allowing social media to enter the classrooms and lecture halls of higher education has been slow due to the majority of educator's scepticism towards the benefits of using social media in a learning environment [63]. Fears of miss-use and being more of a distraction to learning were for the most part the biggest concerns. In a few short years these fears have somewhat dissipated and higher education institutes have begun to write policy and introduce infrastructure for bring your own device (BYOD) to campus [64]. There have been some studies about using social media websites in the classroom [65]. The benefits of using social media as a learning management system (LMS) are things such as; the ability to mix multimodal content uploaded and managed by the learners using any platform (usually the one which is most familiar to the majority of the learner population) and its ability to encourage the quiet students to ask questions online [66].

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[10] http://www.nielsen.com/us/en/insights/news/2010/social-media-accounts-for-22-percent-of-time-online.html. [accessed June 2017].

[11] https://nobullying.com/cyber-bullying-statistics-2014/ [Accessed December 2016]

3.6 Discussion and conclusions

3.6.1 The most important influential factors

Learning theories:

For several decades' theories about how individuals learn have influenced how third level education design and re-design their programmes. The literature indicates that for every educational discipline there are preferred dimensions of learning style, thus the reason why one learner may have a stronger affiliation towards one subject/discipline over another. Felder and Silverman for example, have produced a learning style index (Figure 3.4)[12] to help engineering students identify what type of learner they are and to assist engineering educators to formulate lesson plans that can motivate each of the identified learner types [67]. Accordingly; structured learning of engineering in a formal educational environment is a two stage process [66]. The first stage is considered as the receiving or reception stage and involves CE learners using their senses to observe external information, devise internal information, and consider the sum of all materials presented. The second stage is when CE learners select and process the material before discarding what they consider as surplus [66]. How a CE learner chooses to process can involve memorising, inductive reasoning, deductive reasoning, reflection, introspection and interaction with others [66]. The learning style index developed by Felder et al emanates from well-known theories such as Jung's psychological types [68] (which relates to sensing and intuition) and Kolb's theory to convey active and reflective processing [69].

There are other numerous cases highlighting how higher education institutes implement trends relating to learning theories which originated from the research field referred to as 'the new science of learning' [70]. The strongest of these theories for adult (andragogy) learning, places a high emphasis on experience and in particular experiential learning [71]. Prominent theorist such as Dewey, Lewin, Piaget, Jung and Rogers have written extensively about the experiential process and share a common philosophical view based on six propositions [72]. The six propositions are (i) all learning is a process, (ii) all learning is re-learning (learner belief system), (iii) learning requires conflicting logical discussions and ideas to drive further learning, (iv) learning is holistic, (v) learning occurs through the adaptation of experiences into concepts and vice versa and (vi) learning is the process of creating knowledge [70].

Theorists such as Piaget and Gagne along with Maslow and Rogers are regularly cited in the literature to argue how their behaviourist, humanist and cognitive psychology are having a powerful impact on the teaching and learning of disciplines such as CE at high level institutions. Learning psychology provides the learner and educator with guidance and sign posts (road map) on how to develop mental ability in accordance to each individual's learning style. For learning and teaching of CE for example the literature conveys that by using a cognitive learning approach and acknowledging that factors such as social and emotional influence have an impact on motivation and individual achievement contributes to learners' developing a richer understanding [73].

[12] https://www.mindtools.com/mnemlsty.html

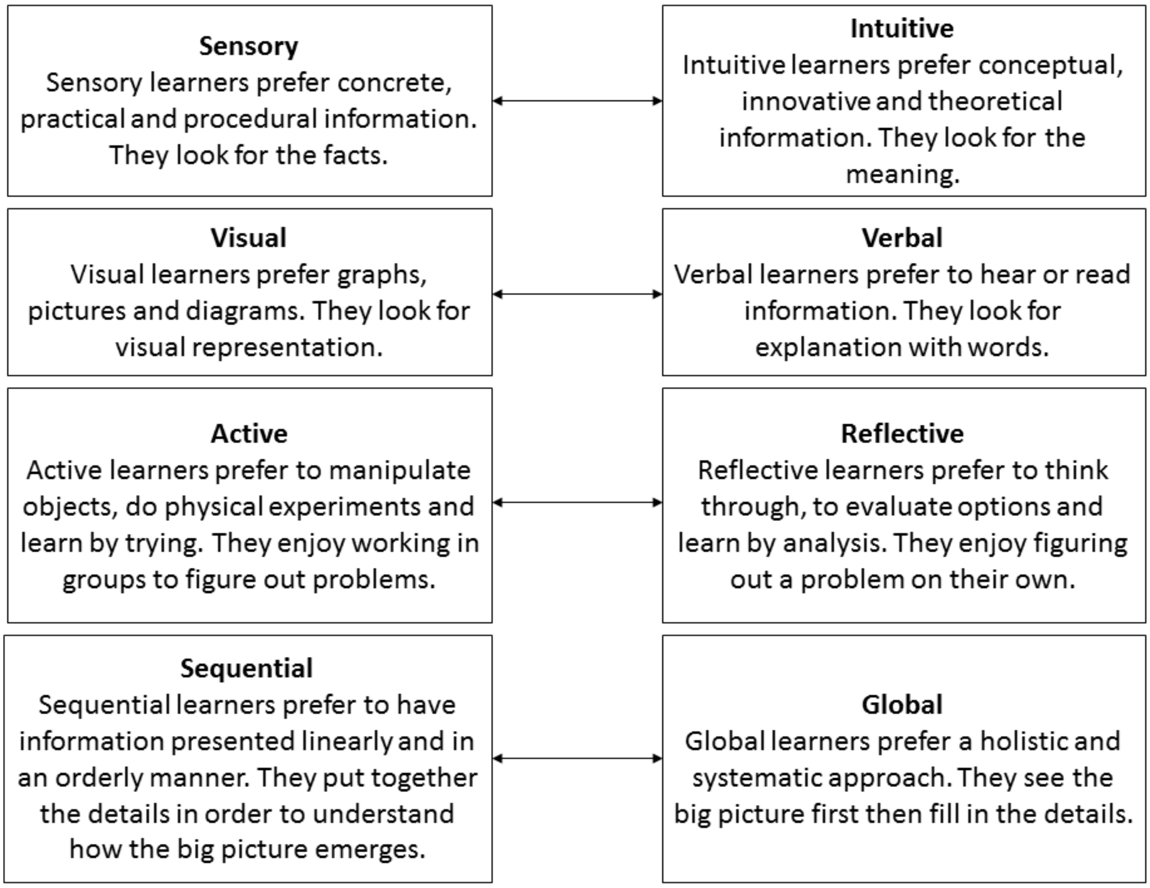

Figure 3.4: Learning style index [66] adaptation © Mind Tools Ltd, 1996-2017.

Motivation:

Intrinsic motivation is defined as the self-desire to seek out new things and challenges [74]. This natural motivational tendency plays a critical role in the cognitive, social and physical development of learners' [75]. It is now accepted that intrinsic motivation is more likely when (i) learners' are given autonomy over their learning, (ii) are exposed to a learning environment which promotes self-efficacy and (iii) are curious about the discipline in itself [76]. Traditionally it was assumed that the motivation towards using computer technology for learning was influenced by extrinsic elements, in recent years it has become accepted that because of the introduction of gaming, VR, AR, social media and digital repositories the use of technology for learning is primarily intrinsic [38]. The result of which has led to a shift towards proactive and context-sensitive personal learning environments' (PLEs) [77]. This shift emphasises the students' role in controlling the educational process. This has in turn raised the need for modelling the student role in the digital learning processes, as well as the relationships to contents, media, and peers.

Extrinsic motivation is the opposite to intrinsic as it is defined as influences exterior to an individual learner that enable that individual to attain an outcome(s) which normally could not be attained by intrinsic motivation alone [73]. When approaching digital learning extrinsic motivation can often be as simple as affording the learner the opportunity to use their current developed skills to complete the digital tasks. Digital learners' like being set challenges in an environment that gives them instant accesses to the knowledge data source that will unveil the information or instructions needed to solve the problem and move to the next more challenging level. The interaction and participation in the construction of knowledge through an instructional design platform provides instant feedback on how their skills have and continue to develop and also how these skills (existing and newly developed) are contributing to achieving the overall learning aims. There is very little literature that provides a theory for the development of a relationship between the user and the system. Reading for example is known to be a pleasurable experience yet very little is written about how authors can immerse readers in carefully described scenarios using a simple paperback book as the immersive technological means [78]. The act of reading is by now an instinctive human skill that no longer merits scrutiny or a requirement to describe how it functions. The same could be said for the technology that surrounds humans in everyday life. The need to describe to the digital learner how the whole enterprise works is therefore no longer a requirement [79].

The learning environment:

There is more to the development of a learning environment than the physical (i) lecturer theatre, (ii) laboratory or (iii) the technological enablers. The literature informs us that learning environments include (i) learner characteristics, (ii) aims and learning outcomes of the discipline being taught, (iii) the content and subsequent activities to support the learning, (iv) the forms of assessment required to measure the number of learning outcomes achieved and the depth of learning (surface or deep learning) and (v) the learning culture [80]. As result when developing VR learning environments the same rules apply. All learning environment types are dependent on (i) content, (ii) structure, (iii) activities, (iv) learner feedback and (v) use of technology [79]. Effectively a learning environment is defined as ‘an educational approach, cultural context or physical location in which teaching and learning occur[13]. For 21st century learning educators and industry leaders have identified higher order skills as key to becoming successful in society and the work place [81]. Educational programs should now be developed or redeveloped in accordance with the term ‘21st century learning environments’ [82]. These environments are learner centred, include the key components of active learning and incorporate the use of technological enablers.

Comfort with using technology:

The 21st century formal learning and teaching is heavily influenced by the level of an individual’s digital literacy. Mobile and personal technology has transformed todays learning, work and social environments. The robustness of these enablers supports collaborative learning, creativity and personalised learning content [83]. The level of uptake in the adoption and use of technological enablers is generally dependent on educational background, socioeconomic status, age, attitude, access and perceived benefit of technology to the individual [84]. It is however evident from literature studies that both 21st century learners and educators use technology regularly for personal use and yet appear to limit or minimise its use during formal education practice [85]. Pan et al verify the importance of comfort and self-advocacy concerning the discernment of the stakeholders towards their preparedness and their effectiveness in using technological enablers for formal learning and teaching means [85]. While the ownership and everyday personal use of technological enablers is considered as an

[13] http://edglossary.org/learning-environment/

important influence towards this, favourable introduction and acceptance of technological enablers for formal learning and teaching is only one of the many influential factors which effect the technology comfort level and self-advocacy for both learner and educator [86].

Other factors considered equally as important include the need to train stakeholders in using technological enablers as tools for developing, creating and collaborating with knowledge as appose to just been used for the delivery and finding of knowledge [87]. Introducing technological enablers to formal learning requires educators being provided with the opportunity to learn how to teach differently than the way in which they have been taught themselves [88]. In recognition of the key role comfort and self-advocacy has towards the introduction of technological enabler learning and teaching tools, assistance has been offered in the form of continuous professional development for educators, by means of (i) the introduction of a community of practice model [89], (ii) the provision of a means to enable learners to assist and teach educators to learn technology [90] and (iii) the provision of postgraduate qualifications for teaching professionals in areas such as applied e-learning[14].

In conjunction with these initiatives is the need for discipline experts who teach to become context aware of the 'new science of learning' [91]. Technological enablers should only be integrated into formal teaching if they are used as meaningful tools that provide more effective learning and teaching [92]. There still remains historical evidence which identifies a lack of comfort on the side of the educator when they are not the most competent user of the technology within their learning environment. This further highlights the importance of effective professional development for educators in the use of technology as pedagogical and andragogic tools [93].

3.6.2 Relationship of the influential factors

The basis of a relationship between learning styles and learner personalities is grounded in Carl Jung's theory of personality [94]. In fact results from numerous case studies have proven that because of how interwoven personality is with learning styles, it actually plays a significant role in the formation of a person's learning attributes [95]. It is difficult to find within the literature a universally acceptable definition for personality, there is however unanimity over five common considerations (agreeableness, conscientiousness, openness, extraversion and neuroticism) which decide personality characteristics [96]. This has led to the development of a number of measuring tools such as the five factor model (FFM) which uses reasoned enquiry based on 'adjective-driven questioning' [97]. The results obtained by such tools confirm the direct 'relationships between learning styles and personality' attributes [98]. Personality accounts for learning behaviour and has influence on the effectiveness of a person's learning [99].

The literature has determined that the learning environment governs the level and difficulty of activities and influences expectations, attention and retention. The essential learning content is accessed by all learners; nevertheless this accessibility is customised to suit the level of involvedness of each of the learner styles at any given time during the lessons [146]. The level and difficulty of the learning activities are segregated using teaching technics such as scaffolding, group learning and encouraging advanced learners to continue as independent

[14] https://lttcprogrammes.wordpress.com/msc-in-applied-elearning/

researchers [100]. The learning accomplishments are a measure of the extent of how much learning is achieved. This measure is scored by providing learners with the means to validate the depth of their knowledge through 'varied levels of difficulty, individual/group work integrated with a scoring mechanism' [100]. The learning environment also needs to be organised to enable learners to collaborate, to work singularly at their pace and to be able to seek help from multiple sources in addition to the facilitator (educator) [101]. Whatever means used to build a learning environment research has confirmed that the learners want it to be (i) engrossing, (ii) to promote direct interaction (peer to peer, learner to educator), (iii) allow the freedom for impulsiveness, (iv) provide instant learner feedback and (v) enable socialisation among faculty and fellow learners [102].

3.6.3 Implications of the conducted study

This study has uncovered the extent to which adult learners are diverse. The literature informed us about how different the principles of andragogy are compared with those of a pedagogical approach. Because of the foreseen diversity of learners, there are four questions that need to be asked in the design phase at designing materials for a learning environment: (i) what should the content consist of, (ii) how should the content be structured, (iii) what order should the content be delivered and (iv) what means do you use to propagate this content efficiently [103]. Consequently in order to provide answers to these questions the typical distinguishing features of individual learning styles need to be considered and an appropriate learning and teaching approach adopted to suit each style of learner enrolling in the learning environment. With this in mind Mouton and Blake have proposed 'synergogy' as a learning and teaching approach to meet the needs of the diverse learning styles as identified earlier [104]. This involves the fusion of the motivational strengths of andragogic learning and teaching approach while at the same time avoiding the known de-motivational attributes of a pedagogical approach when applied to adult learners.

Effectively, synergogy is defined as 'a systematic approach to learning in which the members of small teams learn from one another through structured interactions' [103]. A synergogy approach involves the educator introducing material that will stimulate social learning and enable individual team members acquire knowledge via instructional design facilitation. This cooperative learning approach focuses on stimulating problem solving through the use of team activities. The underling thread from these studies provided evidence that learning styles are diverse and therefore the propagation of knowledge materials and content for formal learning needs to be equally as diverse. From the evidence presented we can deduce that CE in a higher education setting interchanges between the use of a standalone pedagogical approach, a standalone andragogic approach and, when appropriate, engages the principles of synergogy to provide learner centred (i) contents, (ii) an instructional design activity-based structure, (iii) an inquiry-based problem solving delivery, and (iv) knowledge transfer facilitated by an expert educator.

Digital information and communication technologies have resulted in a philosophical change in social, educational and economic organisation [105]. Our study (as outlined in 3.5) has revealed that there is a growth in the number of academics from multiple disciplines examining social media and in particular 'social network sites' (SNS) to gain more insight into user engagement, implications and culture [106]. The literature confirms that there is a 'digital divide' between young people born in early 2000 who have grown up with SNS, their older siblings born in the early 1990's who grow up with the early internet and their parents born prior to the internet age [107]. The digital divide between parent and offspring is all the more obvious when the debates emerge about how SNS practices are producing a generation of learners with a poor standard of literacy skills specifically in the area of spelling and comprehension [108]. The divide is less obvious between older and younger millennial learners as both types are considered as digital natives consistently online, it is in fact their choice of popular digital media or SNS that gives insight into how the current subtle divide is slowly increasing across the millennial generation (Facebook or Twitter versus Instagram or Snapchat) [109]. In reality trying to characterise SNS practice is made all the more difficult because of the wide variation of SNS's and their user types (older versus younger digital natives) [110].

Instead characterisation is generally related to subgroups of digital natives and relates to their understanding, experiences, communication and online literacy practice [111]. Researchers in education, learning technologies, learning science and new literacy for example, have explored the relationship the youngest group of digital natives (13-17yrs) have with the internet, mobile technology and computer games [111]. The general view is that there needs to be a shift on the side of educators from viewing these new digital media (internet, mobile and games) as tools for delivery of content or to enhance teaching, towards a recognition that such media are now representative of social, communication and cultural practices of today's digital learners [111]. With this in mind researchers have investigated beyond print literacy and considered social literacies as shaped by todays (SNS) social practice [147][112]. Digital social literacy requires new skills, approaches, outlooks and social practices that ensures any educator using web-based technological enablers remains mindful that when developing any formal learning programme for higher education the focus has to be on the learners and their individual learning styles and not the technology [113].

Keeping learners focused and preventing them from becoming bored require regular and frequent learning participation by learner and educator. In fact the main role of the educator becomes facilitating interactivity by the learners [114]. Traditionally online learning utilised email, chatrooms and conference call tools as resources to enable dislocated learners to participate online. Today education is encased by an array of new influences such as the use of social media, new mobile technologies and learning and teaching approaches [115]. It is predicated that a new educational balance will begin to emerge once educators master the technic of combining the technologies that comprehend the intricacy of knowledge construction with didactic design that enables all learner types to separate out those intricacies and build new knowledge [116].

Efficacious dis-located learning requires learners to be fully aware of their responsibility in maintaining an active learning plan that includes a self-directed learning strategy [117]. This plan should also identify and include strategies to help overcome low self-esteem or other such personal barriers so that they can use peer to peer learning as a resource. [118]. If dis-located learners are to engage in online activities they need to have (i) the ability to use the technology, (ii) the digital literacy skills to access information exterior to the formal programme and (iii) the ability to exchange ideas online with their peers [119]. Because such skills require (i) a fluency in a shared language (English, Dutch, Spanish), (ii) personal courage and (iii) self-worth, consideration must be given to support learners by providing virtual communities of practice (possibly following the SNS framework/model) to assist them in becoming active and confident online dis-located learners [120].

Accessibility commands that all educational material for formal online learning is accessible via multiple technological platforms inclusive of mobile [121]. ‘Mobile learning’ brings with it many implicit advantages including personal, familiarity, pervasive and ubiquitous, all of which help to reduce accessibility barriers. Mobile learning has been defined as ‘learning across multiple contexts, through social and content interactions, using personal electronic devices’ [122]. New mobile technological devices such as smart phones delineate how the millennia generation send and receive information [123]. In fact there are a growing number of organisations inclusive of cooperate industry and governmental agencies who use mobile devices to manage their information [124]. Traditional modes of learning and teaching have introduced mobile devices and other handheld devices such as clickers into the classroom in an attempt to improve student centred learning [125]. Mobile technology is now at such an advance stage that it is capable of replacing text books, visual aids, and presentation resources [126]. As already stated the ubiquitous mobile wireless internet features of today’s mobile devices ensure learners have access to on demand information delivering a range of opportunities for learning both in and out of the classroom [127]. Mobile learning incorporates a diverse number of distinct forms of learning. It has been defined as ‘processes of coming to know and of being able to operate successfully in and across new and ever changing contexts including learning for, at and through work’ [128].

Learning for work incorporate mobile devices to train staff who are increasingly not expected to work in one geographical location (the office) but are in fact mobile themselves, in health and safety compliance and emergency response training for example [129] [130]. Learning at and through work is usually informal and involves workers using their handheld devices to access information to help with problem solving, customer history or to access mobile decision support systems [131]. Peer to peer interaction across mobile platforms enables features such as ‘people tagging’, this involves co-workers endorsing interests and experience of fellow workers thereby raising awareness and providing a method to help find the right expert on demand [132]. Cross-contextual learning and recognition of prior experience (through learning on the job) provides the link between formal education and the workplace. Mobile devices provide workers with the means to record and document work place learning by means of ‘multimedia learning diaries and portfolios [133]. The learning portfolio are presented as assessment evidence of learning and cross matched with the learning outcomes of formal modules designed to provide learners with workplace knowledge prior to employment.

Dynamic teaching and learning as an approach is a recurring practice that stimulates progress between learner and educator[15]. Introducing technological enablers helps to make dynamic teaching and learning possible to a point whereby learning becomes fluid and the distinction between who is learner and who is educator become blurred. As we have already discussed in section 3.2, the traditional educator centred learning and teaching approach is grounded in the autarchic transmission of knowledge from the educator to the learner [134]. The transference is reverberated in the way learning content and materials have been expanded beyond the reading list of text books [122]. This has introduced the opportunity to develop higher order thinking within the learning environment. However a dynamic teaching approach requires an

[15] http://educationcloset.com/steam/being-dynamic/

understanding of how higher order and lower order thinking vary from one learner type to another [135]. A dynamic teaching strategy necessitates the facilitator (educator) to help the learner make the association concerning the knowledge acquired in the learning environment and how it manifests in the work place/real world [136]. Such strategies are distinguished by the following three notions; (i) a real world connection, (ii) questioning and (iii) group inquiry [124].

Adaptable and focused learning instructions are requirements to assist learners acquire embryonic aptitudes and knowledge to meet industry demands for construction engineering [137]. Digital resources such as learning objects have a fundamental role to play in the drive to make ubiquitous pervasive personalised learning flexible and effective [125]. The ongoing trend is the growing number of open source digital repositories used to store a multitude of learning objects and other such learning materials which can be freely accessed by educators looking for educational resources [138]. In distance learning terms a digital learning object is a digital resource that can be shared and re-used to support learning [139]. Current learning management systems provide an environment for educators to upload, update and share educational material and learning objects [140]. These platforms extend the freedom to learner users who wish to edit such course material. While this is welcomed and encouraged by most it has to be noted that education is not just about access to content [141].

The Internet and other such web-based information technology is the catalyst that has brought about today's smart world [142]. Society is now challenging higher education to provide learners, faculty, and administration with a smart teaching and learning environment which is safely managed [130]. Research evidence demonstrates that there are still teaching professionals who engaged with some of the earlier learning management systems found that there workload increased. The ongoing management and maintenance of the chosen platforms were time consuming. The careful selection and integration of the software systems provided through web services and utilised frequently by the digital learner user group is key to the success of any learning management system [143]. The major characteristics of a Web 2.0 learning management systems are; (i) their built as open access systems, (ii) they harnesses the collective intellect of all users, (iii) they provide the option of security to protect ownership rights, (iv) they allow users to conduct simple programming and couple systems and applications together to suit a user's needs and (v) the host software is compatible with multiple devices[16].

3.6.4 Conclusions

For this research cycle we investigated the influential factors that have a direct impact on the design framework that must be applied when building a (i) learning objects-inspired, (ii) web-based, and (iii) 3D stimulation oriented virtual laboratory for refrigeration engineering training for learner-centred, formal online instructional activities. The identified influences will contribute to testing the conceptual design and build of a refined 3D VR learning application which incorporates a complex 'learner centred approach' as discussed in more detail in Chapter Four. Ideally the conceptual design needed to remain consistent with the influences as outlined in Section 3.6 and in particular comprise of multiple unpredictable events that both engage the

[16] http://www.oreillynet.com/pub/a/oreilly/tim/news/2005/09/30/what-is-web-20.html,

learners' cognitively and affectively, while enhancing their problem-solving skills within the discipline.

As confirmed in Sub-section 3.6.3 a learner centred approach requires our conceptual design to include supports that ensure our learners are given the opportunity to take control of their own learning environment [144]. The scientific approach to research cycle three is documented in the succeeding chapter (four) and provides evidence of our explorations towards the development and design of a blended technological, cognitive and social enablers framework that contributed to the successful development of an effective web-based stimulated learning system (WBS-LS) for distributed construction engineering education. This was pursued to enhance the real life personalised lifelong learning experience of construction engineering learners in the discipline of refrigeration engineering. The conceptual design includes rationale for decisions made based on the most influential trends highlighted in this chapter.

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Chapter 4

Research cycle 3: Conceptualisation of the framework and its use for a web hosted educational system

4.1 Introduction

4.1.1 Objectives

The main objectives for this Chapter were to: (i) synthesise the aggregated knowledge in the form of a conceptual framework, (ii) define the enablers to use as resources for system development, (iii) ideate the system as a synergetic whole, (iv) specify the conceived means of use and interaction with the system, (v) produce a feasible system concept and (vi) guarantee the feasibility and functioning of the system concept.

4.1.2 The research approach

As outlined in chapter one, the research approach was design inclusive research (DIR) consisting of explorative, constructive and confirmative phases. The processed knowledge included (i) theoretical knowledge about educational systems, (ii) empirical knowledge about enablers, (iii) tacit knowledge for ideation and (iv) design knowledge for conceptualisation. The collective ideas for the system were evaluated and where appropriate converted into a concrete concept. This concept resulted from specified functional, architectural, activity workflow, interaction and learning content points of view. The concept feasibility testing was done using critical system thinking. The detailed information flows and structures and the concrete learning contents are specified in chapter five.

4.1.3 The challenges of research cycle 3

The intellectual capacity for the materialisation and exploitation of ideas and concepts for technological enabled stimulated learning, social science enablers and cognitive science enablers, required a knowledge-intensive high level of abstraction [1]. Literature has shown that there are countless detailed methods and technics to support product conceptualisation. There are also several known definitions that describe what is considered as conceptual design. All of which added to the difficulty of providing an acceptable concrete unequivocal and definitive description of our conceptualised design [1].

In addition the author of this dissertation was an academic manager for CE programmes being taught at a third level institute. This meant that the conceptual model to illustrate how the design

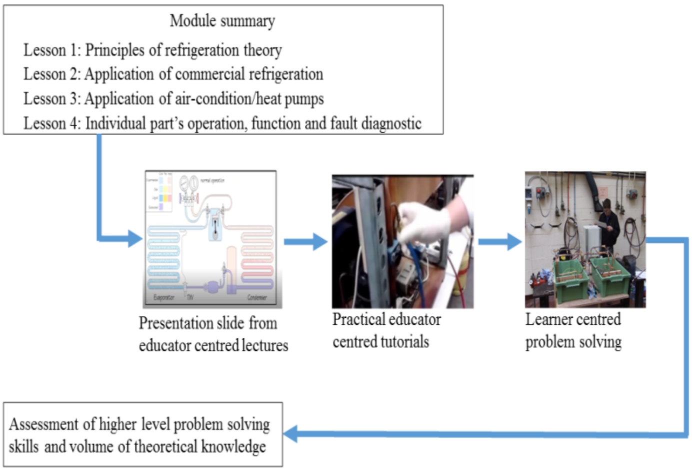

Figure 4.1: Process flow for current delivery of module

solved associated problems with teaching distance learning CEE online, seemed to be nebulous because domains of the design were reliant on the researcher's presentiment. Transferring the intuitive theoretical knowledge into a practical realisation required the author to consider the compatibility of theoretical techniques with the specific functions of the design. This required the author to find a means which could communicate how the professional knowledge and digital literate skill of construction engineering educators should bridge the gap between the theory of web-based learning in CE and the practice.

4.1.4 Developing a process flow

The further development of the cognitive idea of a system that gave learners the opportunity to practice learning remotely into a conceptual design needed an educational context. With this in mind and the fact that the origins of the idea came about as a direct result of the challenges, problems and issues experienced by this researcher the educational context was based around a refrigeration engineering learning module. The majority of the learners for this module are either part time learners retraining because of employment commitments, or full time learners that do not learn effectively in a classroom type setting, mostly due to compatibility issues between their individual learning style and the current teaching approach applied to this module.

Higher education institutes deliver formal education by means of a 'semesterised' system in which subject disciplines are broken down into manageable modules. As it is generally known, a semester is a period of time not exceeding six months while a module is (i) a description of the subject, (ii) the learning aims, (iii) the objectives employed to ensure the learning aims are met, (iv) the desired learning outcomes, (v) the assessment technics employed to confirm learners have met the learning outcomes and (vi) the recommended essential and non-essential reading/learning material. The rationale for introducing modularisation into formal education and training is in response to the growing need for flexible learning solutions to meet both individual learner and industry needs [2]. The refrigeration training module in this case can be completed solely for the purpose of up-skilling (retraining for employability) or as part of a suite of modules aligned to a formal construction engineering degree.

The current method of delivery for the refrigeration engineering module involves learners spending 1 full day per week on campus for up to six weeks. The delivery of this training is through a combination of lecturers, practical skills demonstrations and individual portfolio development, the specific details of delivery content are outlined in Chapter 5. Figure 4.1 is a flow diagram illustrating the process flow of the current means of delivery of the module. Learners receive: (i) a set number of classroom based educator centred lectures followed by (ii) a number of training laboratory based educator centred practical tutorials before progressing onto (iii) the purpose built equipment for learner centred problem solving training and fault diagnostics and finally (iv) the learners must provide evidence that they have met the module learning outcomes, this is done by completing theory and skills assessment exams.

To assist in the identification of a concept structure, a systemised exploration and composition of applicable concepts was employed [1]. Figure 4.2 is an adapted waterfall process model used to arrange the activities that lead to the forming of the concept structure [3]. The idea forming for a conceptual structure focused on reproducing the real world laboratory based learner centred problem solving training and fault diagnostics in a virtual environment. The virtual environment needed to afford learners the opportunity to work with refrigeration system components and complete learner centred problem solving activities that invoked higher level thinking. This required it to have the means to enable a beginner to progress as a pervasive learner, ensuring acquisition of speedy and accurate problem solving higher level thinking in refrigeration and air-conditioning systems.

The requirement specification therefore was that the virtual learning system needed to be (i) easy to use, (ii) to have realistic graphics and (iii) to offer a progressive learning approach. The virtual components needed to be graphically realistic and to simulate student centred learning activities conducted by learners in the real world training laboratory. The system needed to enable interactive and somewhat intuitive learner feedback. The functional specifications was that the system could (i) virtual replicated components to act as learning objects, (ii) enable educator to learner and peer to peer learning, (iii) capture and store learner data, (iv) enable ubiquitous networked connectivity for multiple user communication, (v) provide access to and store learning materials.

The exploration of tangible resources progressed from evaluating software to identifying enablers that would provide a realistic virtual reproduction of the learning processes that takes place in the real world training laboratory. he operational requirements was that the system used a web-based platform as a central place for learners to log on and (i) access files such as

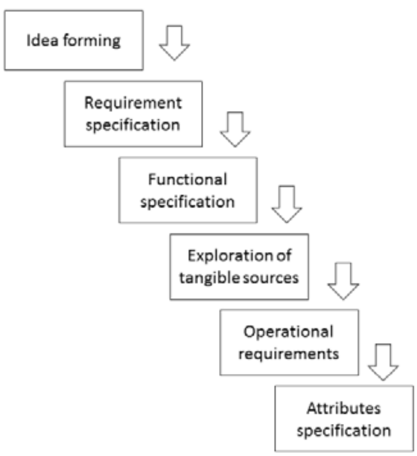

Figure 4.2: Waterfall-type process model

learning materials (ii) download software to allow their hardware device become compatible with virtual environment software and (iii) log on to the multiple user communications network.

As far as the technological and societal developments are considered, we discovered and published in our forerunning state-of-the-art literature review paper that detailed simulation of procedural construction engineering activities is now possible as a result of the development of virtual reality (VR) and augment reality (AR) hardware and software, and that their number is growing in this area [4]. There are numerous case study examples in which 3D VR and/or AR applications were applied as construction engineering learning tools in an attempt to help solve the learning problems for many students and increase their success rates with regard to training and understanding. However, our research also revealed that these VR and AR simulations and their environments did not necessarily enhance students' problem-solving or higher-level thinking skills. As outlined in our paper, which studied the use of game engine technologies for increasing cognitive stimulation and perceptive immersion, technology driven simulated education often runs the risk of been overly bias towards the technology platform [5]. As a consequence of this, there is limited uptake to incorporate game-based VR technology-driven simulations into construction engineering education.

The novelty to our conceptual idea is that the emphasis was on the application of technological, cognitive and social enablers. The conceptual structure, shown in Figure 4.3, provides for a seamless integration of these enablers. It is our contention that the main requirements of the enablers is to (i) motivate students, (ii) provide perceived usefulness (iii) ensure rich knowledge transfer, (iv) enhance problem-solving skills and (v) develop higher level thinking skills. A crucial issue for the implementation of the multi-enabler based idea was the realisation that digital learners are not specifically about the technology, but are more about the activities and experience that the technology provides [6].

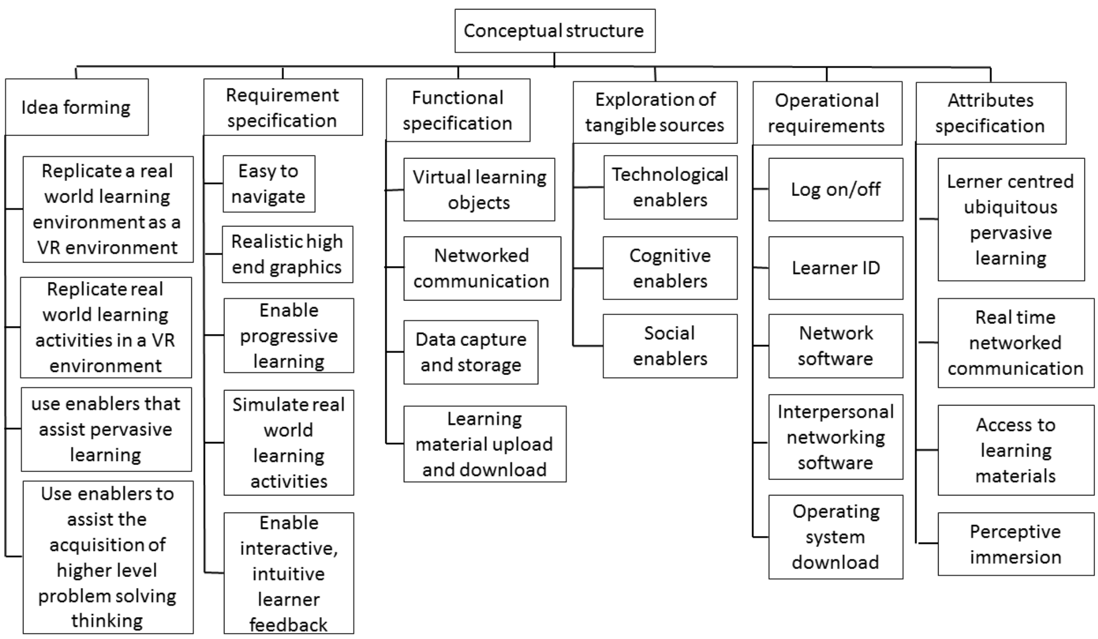

Figure 4.3: Conceptual structure of the WBS-LS

4.2 Ideation of the web-hosted learning system

4.2.1 The operational objectives and requirements

The objectives for the website operational requirements was to develop a number of information pages and content to include typical features expected from web-based learning platforms [7]. In addition to web page content it was also a requirement for the website to facilitate the uploading and downloading of VR and AR software files to and from the learner's hardware devices. The conceptual design for these files was to combine their function with that of a cloud based web host service to track the interface activities of each individual learner. This tracked data could then be stored each time a learner logged off and recalled again sometime in the future. For example each time a learner logged back on, using their unique username and password, the web host needs to be configured so that it recalls the stored data attached to the learner profile and use this information to ensure each learner is returned to their last point of exit. Typical information that needed to be stored for individual learners includes (i) number of questions/tasks attempted, (ii) last question/task attempted and (iii) the length of time spend on each question/task.

The operational requirements for the management of the user activity database can be provided through an information stream processing service via a relational database management system (RDBMS). Put simply, the service takes structured query language (SQL), files held in the RDBMS and sends them as HTML files to the website. Figure 4.4 is a conceptual processing diagram of the architecture models required to build the prototype website. This architecture highlights how such a prototype (i) supplies, (ii) stores and (iii) manages the relevant files over the network to ensure the user commands are reflected accurately. The website design requires that it provides for networking and to play an instrumental role for the network management of the system. To provide the functional requirements we needed to develop 3D virtual

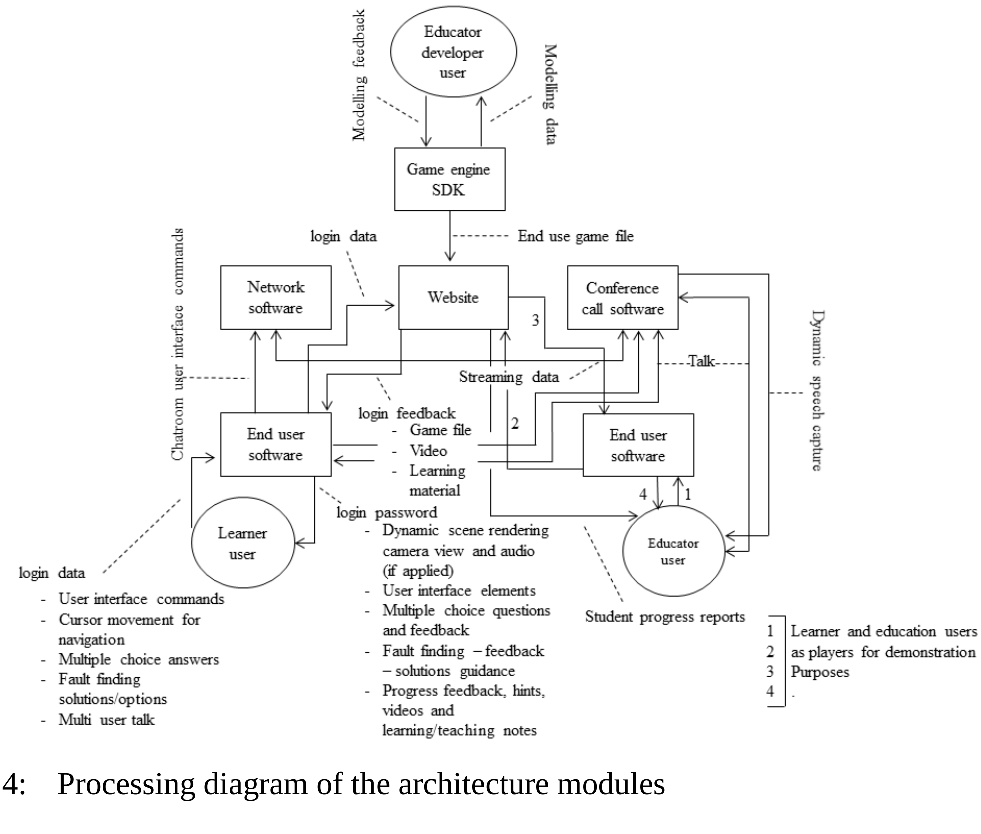

Figure 4.4: Processing diagram of the architecture modules

models/objects. The literature guided us towards the use of game engines because of their refined software development kit (SDK) and towards 3D modelling software because of their context rich graphics and ability to keep file sizes small. Modelling software for example is used to create the more complex constituents of the virtual environment, provide animations when needed and still maintain a small file size for transportation across the internet.

The overall objective is to synthesise the aggregated knowledge to design a conceptual prototype of a novel and more effective system for distributed construction engineering education. As a first step in the development process our cognitive idea into a conceptual design to establish an enabler integration and processing model for the system, followed by a multi-aspect conceptualisation and concept testing. Setting up the theoretical framework is partly based on an extensive literature study of the current state of the art and trends of web-based construction education. It also involves the investigation of the existing and emerging technological and other resources of system development, and processing the requirements collected from multiple sources. Partly, the conceptual processing model is constructed based on the concrete practical experiences of this researcher concerning distributed construction engineering education and the experiences of the supervisory team concerning the implementation of web-hosted information systems for educational purposes.

The overarching idea is that the novel system should include more than just the latest technologies and system operation architectures. Actually, it is supposed to blend various technological and non-technological learning enablers, and to consider the personal characteristic and learning style of the individual and community learners of our digital era. That is the reason why our research addressed the issue of educational enablers in a broader perspective. Rather than focusing only on the technological ones, we identified complementing enablers, which can effectively engage digitally literate students in problem-driven learning processes, considering their individual needs, capabilities and circumstances. In this chapter we primarily concentrate on conceptualising the first phase of system development, which is the conceptual processing framework for the novel educational web-based system for CEE.

Based on the results of the completed knowledge synthesis, it has been hypothesised that the solution can be a complex web-based, stimulated learning system (WBS-LS) that is able to support multiple, unpredictable learning scenarios which will engage the students both cognitively and affectively, while enhancing their problem-solving skills within construction engineering education. As explained below, the concept WBS-LS has been designed considering the application of technological, cognitive and social enablers. The system is required to provide a seamless integration of these enablers. It is our contention that the main attributes of the enablers is to (i) motivate students, (ii) provide perceived usefulness (iii) ensure rich knowledge transfer, (iv) enhance problem-solving and (v) develop higher level thinking skills when presented with unfamiliar scenario problems.

Technological, cognitive and social enablers have not yet been utilised in integration and to their full potential in construction engineering education. Our related assumption is that a proper identification and synthesis of enablers will make a substantial difference in how students perceive and interact with the WBS-LS. Implemented by using a commercial programming environment, the proposed WBS-LS relies on a specific methodology that synthesizes the abovementioned enablers. This is shown in Figure 4.5. On the other hand, this scheme can be interpreted as a reasoning model concerning the development process in as much as it allows us to transfer the need as stated in the beginning of this paper to a first workable prototype. The key to this reasoning model is to ensure the androgogic/pedagogical integrity is maintained when utilising technological enablers for stimulation of practice based construction engineering activities. The prototype needed to provide student learning and virtual stimulation of the senses equal to the experience of co-located learners when they are participating in normal face to face (F2F) laboratory-based activities. It has also been considered that game engine technology can support virtual learning simulation based on realistic problem scenarios, as it is known from the literature.

The attributes of this type of learning environment for dislocated learners are that it (i) permits engagement with a subject matter, (ii) allows for individualism, (iii) caters for a varied learning pace and (iv) provides instant 24 hour access to large amounts of information. Our web-based platform was conceptually designed to provide challenges to test learners understanding [8]. The visual interface design incorporates a 2D flat screen perspective. The learner controls a camera and navigates the VR environment by moving the camera view around the parameters of the flat screen. The specific requirements for this conceptual framework was to (i) utilise current technological, cognitive and social enablers and develop a framework for learning, (ii) provide a web-based educational system which easily integrates technological enablers (such as (a) handheld mobile ubiquitous devices, (b) real-life networking, and (c) multi-user communications) with cognitive enablers (such as (d) video game induced stimulus and (e) task driven problem solving,) and with social enablers (such as (f) interpersonal networking, (g) personalisation and (h) individualism). To use this conceptual enabler framework and build

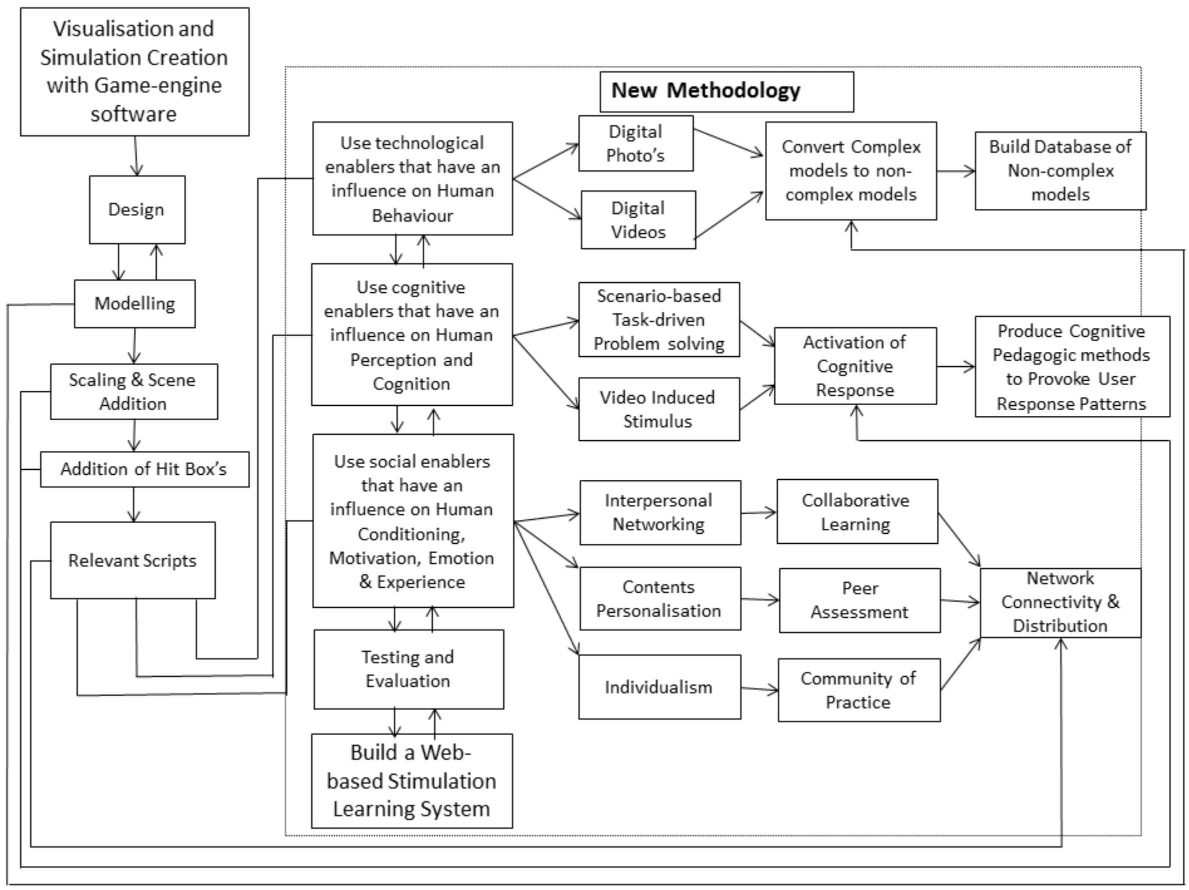

Figure 4.5: High-level enabler integration and processing model of WBS-LS

a working prototype we choose to use (i) game engine navigation software, (ii) game engine controls software, (iii) online storage software and (iv) browser embedding software.

4.2.2 Introduction and definition of enablers

The term ‘enabler’ has been defined as: ‘means to equip someone or something with adequate qualities, capabilities, power, opportunity, or authority to do something’ [9]. In line with the objectives of this research cycle, we identified and used three categories of enablers: (i) technological, (ii) cognitive, and (iii) social enablers. They were selected as a means to increase the efficiency and personalisation of learning for millennia learners when applied individually, but even more, when applied in a complementing manner. As the name implies, technological enablers are instruments and other engineered solutions that simultaneously provide learner-centred, community-centred and assessment-centred supports for learning processes and/or environments. They are PCs, laptops and hand held devices, and the related networking, communication, storage and visualisation devices.

Cognition is defined as ‘the mental process of knowing, including aspects such as awareness, perception, reasoning and judgement’ [6]. Cognitive enablers are defined as content-centred pedagogical and didactic means, methods/methodologies and techniques that interact with the mental and perceptive domains of the learners and provide the support needed for the learner to construct knowledge. By definition, social enablers include those community centred means, supports and arrangements, which enable group-based, peer-assisted, learner-centred active learning. While these enablers were used in separation and to a very different extent in the traditional learning systems and environment, our cognitive idea was to blend them and make the best use of their complementing nature.

Consequently, one of our operative research interrogations was about the selection of the correct cognitive and social enablers, to ensure they had the potential to assist technological enablers to stimulate the richness and intimacy of information exchange which exists naturally in the real classroom. The assumption was, that if progress was achieved in this direction, it would largely contribute to the creation of a learner centred web-based platform that could be concurrently accessed by a large number of dislocated learners and educators. The functional concept of the system was a conceptual design to facilitate both individual and group-based learning and to cater for the participation of both traditional and non-traditional learners. To implement the proposed WBS-LS we proposed a design that combined the enablers in a way that made it possible for the learners (i) to learn in permanent teams or in any volatile formation, (ii) to achieve personal results while cooperating with peers, (iii) to experience an image rich environment, (iv) to enhance interactivity and connectivity, and (v) facilitate learning by doing [10].

Enablers can be classified as prevalent and emerging enablers. The prevalent technological enablers are the results of the research and development extending back two decades, while the emerging ones became known and started to spread just in the last couple of years. Obvious therefore that those belonging to the first class, such as internet-based networking, mobile communication, cloud/grid computing, mobile software platforms, knowledge ontologies, social websites/media, and so forth, have been applied and tested in various educational systems. Actually, they together created a robust base for what has been named as technology-driven online educational environments. Since the variety of these technologies is extremely large, we can do nothing but to cast light only on the most influential and dominant ones in this subsection. In addition, we also provide a brief account of the currently used cognitive and social enablers and how they have been applied. The next subsections will address the same issues from the perspective of the emerging enablers. However, we will discuss them only in the context of CEE.

4.2.3 Currently used enablers

Technological enablers are the main generators behind technology-driven education research. Contrary to the time of existence and the continuing growth of technology, this field of study is moving at a slow pace and the integration of technological developments into the daily practice of CEE remains below the expectations. Application of specific enablers and functional affordances are most often motivated by the technology potential, resulting in social enablers, cognitive enablers and validated educational theory being somewhat ignored [11]. The many and varied courseware, designed and implemented for construction engineering learning and teaching have proven effective for increased learning and overall engagement. The use of technological enablers has proven to enrich subject content and study materials for learners [12]. It also facilitates and enhances peer to peer learning and fosters individual creativity and innovation [13].

Technological enabled hardware and compatible software is widely employed to support simulated training and for the development of virtual reality environments. VR generally conjures up images of completely immersive environments for most people. For the digital millennia, VR is a set of technological hardware and software enablers combined to trigger many depth cues, such as sound, motion and field of view [14]. However, due to commercialisation, it has lost its uniqueness and novelty, with the exception being the immersive stimulation, which is based on the visual degrees of vision provided to the viewer [15]. This sense of immersion is what is associated with cyber-psychological learning benefits [16]. While many of the immersive 3D interface technologies are still under development, the availability of technological enablers such as: (i) 2D image editing, (ii) animation, (iii) computer aided design (CAD), (iv) interactive 3D visualisation, (v) entertainment, and (vi) video games, has largely increased in recent years [17].

The cognitive enablers for web-based learning tend to be overlooked as developers are more focused on the technological capabilities. The most common cognitive enablers used to support learners in web-based education are: (i) conceptual enablers (the provision of hints and/or recommendations), (ii) meta-cognitive enablers (assisting learners to plan and reflect), (iii) procedural enablers (supporting learners to conduct tasks and experience) and (iv) strategic enablers (supporting learners to apply their knowledge and competence) [18]. Our experience is that these cognitive enablers have shown their potential when applied in close combination with technological enablers. Their potential is more often overlooked due to the developers need to simulate realism as appose to stimulating a learning experience for the intended user.

Web-based *social enablers* are also very much dominated by what the technological enablers have to offer. Current web-based social enablers encourage and foster human to human interaction singularly or within large groups, and provide a virtual sense of community in real time [19]. Web-based social activities are an enriched source of communication [20]. Web-based social enablers are now about (i) conversations, (ii) interpersonal networking, (iii) personalisation and (iv) individualism. Social enablers are feeding the growth of digital learners in the 21st century [21]. The digital learner use web-based social enablers in a collaborative way to better understand and learn or simply to get help and understanding through others [22].

4.3 Advanced and emerging enablers

4.3.1. Advanced and emerging technological enablers

Emerging technological enablers includes various analogue and digital hardware, control, middleware and application software, and cyberware as media, coded knowledge, information structures, and data contents. The family of digital hardware means ranges over (i) computing, (ii) visualisation, (iii) networking, (iv) actuation, (v) communication and (vi) sensation conversion means. To some extent, these have already been embedded in everyday mobile and wireless applications as enablers. In addition, they have also been instrumental in bringing about an increased trend towards pervasive and ubiquitous computing (PUC) [23]. PUC is the embedding of microprocessors into everyday objects to allow information exchange [24]. It is as a result of PUC that the phenomena of pervasive learning (learning that is available anywhere anytime) has developed [20].

Due to miniaturisation, low prices and costs, and remarkable functional capabilities, these technologies contributed to the development of deeply embedded systems, Internet of (every) thing(s) systems, cyber-physical educational systems, and even of educational (assistive) robotic systems and applications. While in the past, hardware and software development were two separate domains with extensively different cultures and skill sets, today hardware, software and cyberware co-development seems to have become a daily practice. Based on sensors and wearables, current systems try to penetrate into real life educational processes and gather real time data to inform and improve educational decisions and practices. Additionally, coming up with effective ways of visualising content, process and individual related raw and synthesised information has become crucial. Though software-triggered servitisation, much of the hardware- and software-linked functionalities can be provided as network accessible services.

Software as emerging technological enabler is an endless fountain. Though various (i) ad hoc network management software technologies, (ii) software prototyping environments, (iii) software component libraries, (iv) three-dimensional graphics and modelling tools, (v) web contents authoring tools, and (vi) game developer software tools, have emerged onto the markets and into more and more applications. In fact, the major progression is in application software (apps) development. Thousands of education oriented apps can be purchased or downloaded to smart mobile devices. Advanced analytical tools have also been developed that benefit from hardware and software sensors, and support big data analytics and pattern/semantics exploration. Real-time translation is becoming a widespread reality, opening new opportunities for cross-boundaries education in CEE. As technological enablers, cyberware, web content and media materials provide opportunities for both educator-centred as well as learner-centred synchronous and asynchronous collaboration [25].

4.3.2 Advanced and emerging cognitive enablers

When involved in learning, students have their own perspective and experiences whereby they construct their own interpretations of the knowledge provided to them [26]. This can be exploited in the conceptual design of our WBS-LS; learners construct their own interpretation from the simulation of realistic scenarios of real time events. Cognitive understanding of a stimulated event determines an individual's perception of the event. Research suggests that a learner's perception highly influences the way students retain information especially during complex cognitive tasks [27]. The social makeup of learners and their relationships are influenced by the surrounding environment. For enhanced cognitive responses the key design ideas are (i) the learner must be allowed to develop critical thinking (meta-cognitive enabler), (ii) the ability of problem solving (procedural enabler) and (iii) the learning environment must operate as an interacting system between the teacher and learner, vice versa and also between learner and learner (strategic enabler) [28].

The provision of a graphical user interface (GUI) that convinces the user of their presence when navigating through the 3D space, invokes actions and reactions equal to real time experience [29]. In other words the sense of presence experienced invokes cognitive responses equal to real world experiential actions and reactions [30]. The GUI plays an essential role in invoking intrinsic motivation which is linked to cognitive engagement in learning (because it keeps the learner's attention focused), new knowledge is learnt in a meaningful way (deep learning as opposed to rote or surface learning) and knowledge gain is achieved at very high levels. The evidence emerging from recent educational literature provides proof that when students are given the opportunity to personalise and control learning content, their learning achievements are increased significantly [31].

Self-regulation is when the students monitor the success and the weaknesses of their learning [32]. This involves the student invoking strategies and technics in an active learning capacity to gain comprehensive understanding of the subject matter [32]. Serious game theory when applied to web-based education is intended to help: (i) student learning, (ii) their ability to problem solve, (iii) their development and improvement of cognitive and social skills [32]. The digital learner are constantly interacting with video games which have been designed to engage and motivate users to improve their skills and progress there problem solving cognitive knowledge. In contrast to the traditional teacher centred learning model self-regulated learning is a natural paradigm for digital learners.

4.3.3 Advanced and emerging social enablers

Real world construction project completion is dependent on both the physical and the social sharing of problem solving activities. The rapid advancement of screen-based technological enablers provided the opportunity to investigate and confirm the fundamental principles for applying screen-based online web-based socialisation. These technologically enhanced social enablers now play a vital part in the creation of socialist cognitive stimulated learning. The sort of problem solving carried out simultaneously within construction industry real world environment is very distinct from processing of ideas solely inside one's head. Extensive research has shown many examples of screen-based technological enablers being used to store and make information available and contribute to a learner's self-construction of knowledge [33].

Examples of when social enablers have been included as equal to the technological design are limited and incomplete. Screen-based virtual simulation has proven effective in procedural skills education [34]. AR/VR visualisation provides learners with an opportunity to work with models of the real world environment in a virtual world. This in turn is intended to stimulate cognitive skills growth. The simulation of procedural tasks is intended to give the learner a chance to develop and refine their skills through repetitive practice in a learner-centred highly socialised pervasive and ubiquitous environment [35].

The latest generation of communication technological enablers has radically changed how knowledge is development and disseminated. Education plays a major role in knowledge dissemination and development and therefore should wisely apply and integrate the available and emerging affordances [36]. Web-based social activities are an enriched source of communication [37]. Web-based social enablers encourage and foster human to human interaction singularly or within large groups, and provide a virtual sense of community in real time [38]. Today's construction engineering design and build practicing professionals are heavily influenced by the need to provide perceptual immersion for their clients. They do so using hardware and software tools (technological enablers) combined with abstract thinking (social enablers) to create a real world look and feel (cognitive enablers) inside a virtual world.

The interactive communication social enablers used by construction engineers on a daily bases are (i) social communities, (ii) scientific forums, (iii) VR environments, (iv) process control, and (v) business conferencing. Social enablers are born out of evolving computer technological enablers and a human desire for global synchronous and asynchronous communication. Web-based networking as a social enabler provides an infrastructure network that is capable of (i) receiving various types of content from the users and (ii) supporting communication among large volumes of users thereby supporting the formation of autonomous virtual communities [28]. Where there are social frameworks such as web-based communities of practice which are not overly reliant on each other. The interests of the individual's take precedence over the group or web-based community's interests. Individuals are encouraged to communicate their opinions regardless of the counter opinions. It is believed that by speaking out and articulating ones view that one can evaluate ones learning (learning to learn) [39].

4.3.4 Possible integration of enablers

It is our belief that the most influential technological enablers that should be considered in the conceptual design process of a WBS-LS are: (i) network management facilities, (ii) developer game engine SDK, (iii) scene and object modelling software, and (iv) digital photography and video. The traditional concept of learning has now been changed. Digital learners are constantly being surrounded by and immersed in learning experiences [40]. The influence of pervasive learning will be embodied in our novel WBS-LS through the above selected technological enablers. Software development kits (SDK) are available for game developers by which they can encourage community knowledge sharing, and asset storage. They are compatible with universal hardware means. These technological enablers have had large influence on commercial product/system development, but also on human behaviour.

How effectively one learns is based on the experience, perception and psychological state of mind, therefore the principle of our reasoning framework is that the selection of cognitive and social enablers will determine the selection of the technological enablers needed to stimulate human learning. We stated earlier that our conceptual framework is intended to provide student learning and virtual stimulation of the senses equal to the experience of participating with normal face to face (F2F) delivery of procedural based workshops. Digital learners have proved that it is not effective to try and reproduce traditional classroom-based learning through software utilisation. Our idea is for a framework that functionally integrates the technological, cognitive and social enablers into a WBS-LS. The literature confirms that the success of the design will be bench marked against how well it can produce (i) temporal dissociation, (ii) focused immersion and (iii) heightened enjoyment [25]. In order for this to take place the system must meet with the requirements of (i) perceived usefulness (the extent to which individuals believe that using the system will enhance performance) and (ii) Perceived ease of use (the degree to which it is believed to be effortless) [41].

Designing our WBS-LS to meet with the above requires us to blend (mixing the components together) the cognitive with the social enablers with the dominant technological enablers until they are no longer distinguishable from each other. Essentially we wish to bring together the real technological enabler tools (hardware/software) with the abstract cognitive enabler and social enabler tools to create the perception of the real world inside the virtual world. Figure 4.6, illustrates the linkages between technological cognitive and social enablers. Technological software and hardware provides us with the ability to construct knowledge and enable cognitive perception for the digital learner. An understanding of cognitive behaviour in learning environments assists in the design of VR learning spaces. The cognitive enablers should be closely linked to or embedded within the technological and social enablers. How digital learners now use both technological and social enablers has had a direct effect on their comprehension and cognitive development.

4.3.5 Presentation of the system idea

As a technological enabler the literature has determined that the SDK for game engine web-based platforms can provide us with the means to produce (i) visuals, (ii) control, (iii) communication, (iv) interaction and perceptive immersion for our virtual workshop. In order to provide virtual stimulation of the senses equal to F2F experience we used digital photography and recordings to capture the look and sensation of real time interactivity within the real world workshop. Figure 4.7 is the workflow process to build the technological enabled requirements for the WBS-LS. Because most, if not all, handheld mobile devices have a digital camera embedded in them, digital learners use this technological enabler to share visual experiences with their peers across a range of interpersonal networked web-based platforms. Therefore it is our contention that digital images have an influence on (i) human perception and cognition, (ii) human condition, motivation, emotion and experience and (iii) that this influence is universal to digital learners because such images are networked across web-based systems frequently with little effort. Another reason for using the digital camera which is a technological enabler is because of its influence on cognitive and social enablers for digital

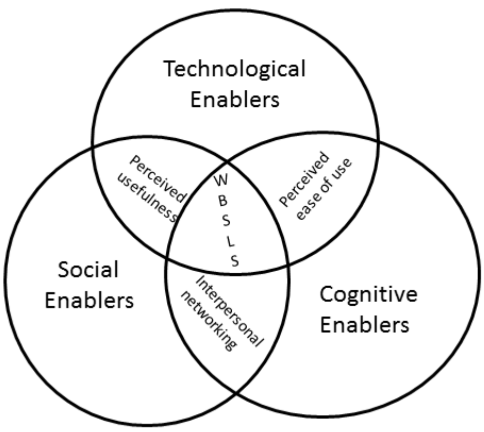

Figure 4.6: Linkages between enablers

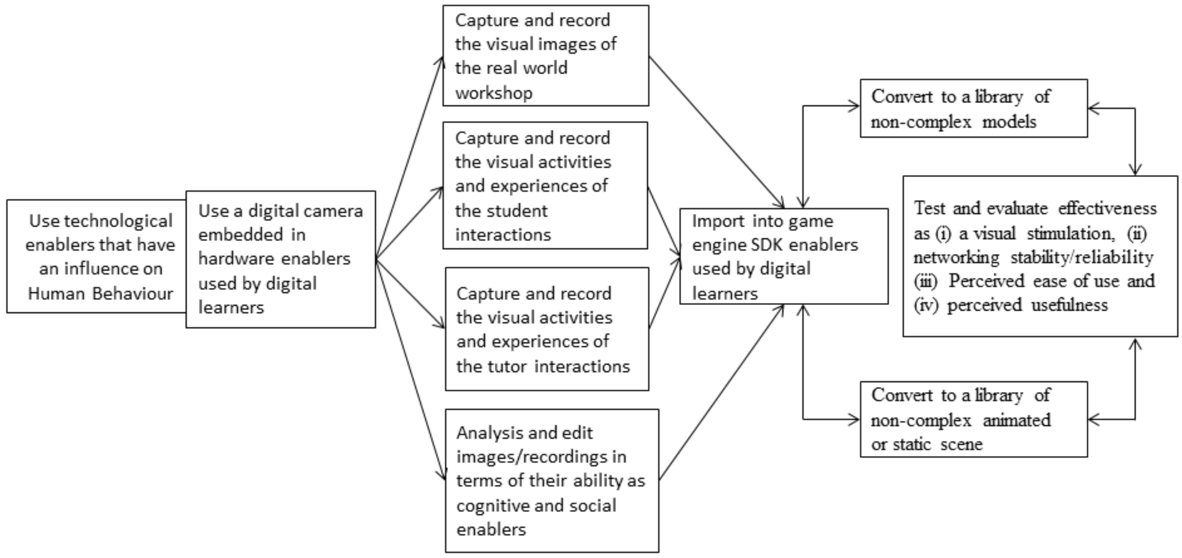

Figure 4.7: The workflow when using technological enablers

learners.

Theorists such as Piaget and Gagne along with Maslow and Rogers are regularly cited in the literature to demonstrate how their behaviourist, humanist and cognitive psychology theories impact on teaching and learning. Learning psychology provides students and tutors with an explanation of how to develop mental ability in accordance with an individual's learning style. There is strong evidence that a cognitive learning approach and strategy combined with an acknowledgement of the impact social and emotional factors have on motivation and achievement, will contribute to a richer understanding of individuals development [42]. The construction engineer needs to develop techniques to identify and resolve problems. They are motivated to learn these techniques because industry require personnel who have the ability to provide solutions to problems under pressure from client demands and work completion timelines. From the developed and emerging cognitive enablers, Figure 4.8 shows the applied workflow of using cognitive enablers, which considers the use of (i) learning induced stimulus

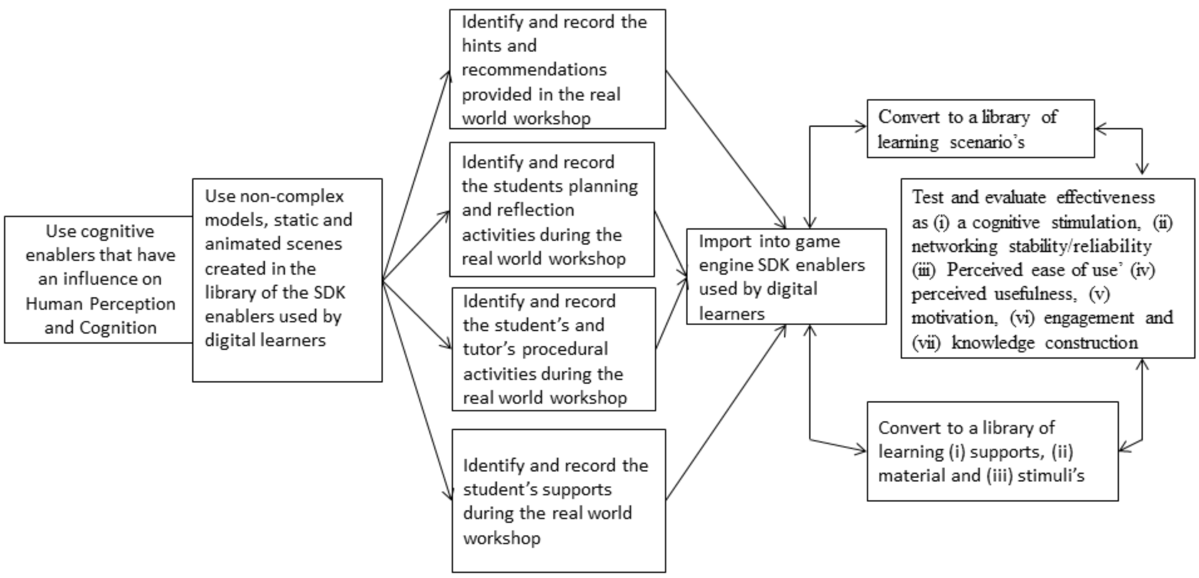

Figure 4.8: The workflow when using cognitive enablers

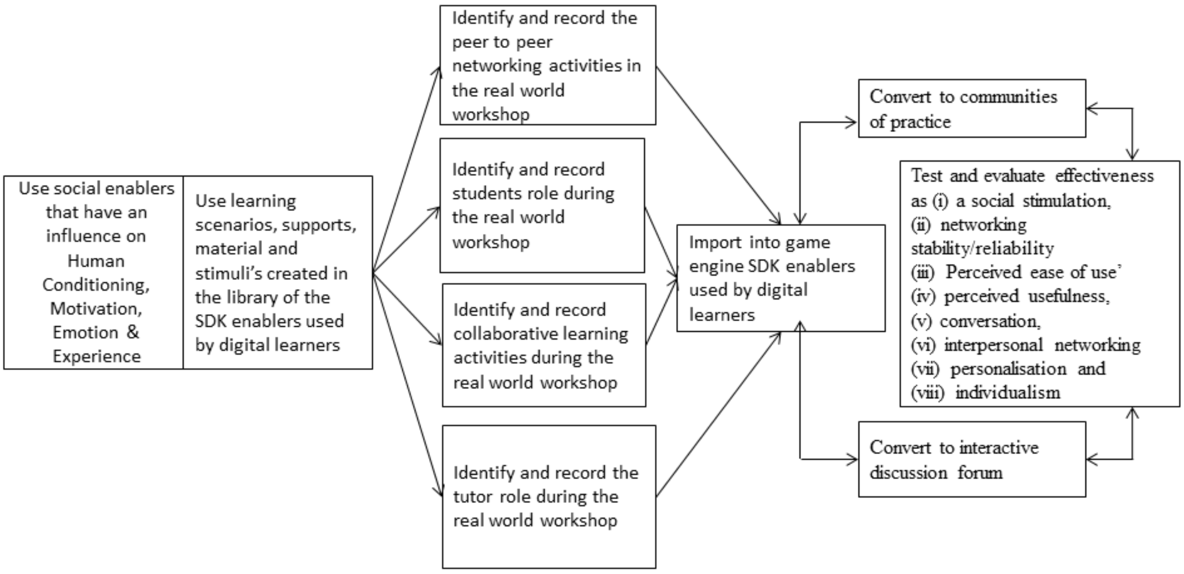

Figure 4.9: The workflow when using social enablers

(conceptual), (ii) task driven problem solving (procedural), (iii) active participation (meta-cognitive), and (iv) individual response patterns (strategic).

Online video is a popular form of stimuli's as a social media enabler and is often used both in the classroom and outside of the classroom when students need to gain further information [13]. Ubiquitous web-based networking is strong enough to support and provide a web-based infrastructure network that is capable of (i) receiving various types of content from the users and (ii) supporting communication among large volumes of users thereby supporting the formation of autonomous virtual communities [43]. Research has proven that social media sites add value to teaching and learning [44]. Figure 4.9 shows the workflow of using social enablers.

Communication plays an important part of virtual socialisation. If the WBS-LS is to be effective it must allow for more than one person interacting within the environment. Interpersonal networking provides a means for communication between those with common interests. The interpersonal network provides an easy method to share information and further discuss it. The use of mobile technological enablers will ensure the students can expand their learning environment into their world of web-based social networking.

4.3.6. Testing the system idea with a focus group

The details of this research proposal were presented to a focus group at the Tools and Methods of Competitive Engineering (TMCE 2014) Symposium. We presented a digital recording of a standard educator centred tutorial that took place in the real world training laboratory. We used this as a visual aid to explain how our conceptual design would virtually replicate learner and educator experience and create a more augmented experience for dis-located learners accessing the laboratory by remote means. The enabler work flow models were also presented for debate and discussion. The group of expert peers from computer science, engineering and education discussed and evaluated the theoretical dimensions for appropriateness and validation. Consideration was given to the proposed theory set and consideration given to whether or not a new set of theories were required. Emphasising that the focus was not the technology itself and more about ways of applying learning using the technology for dissemination, the group explored the presented concepts of enabler scenarios relating to the refrigeration engineering training laboratory based on (i) cognitive enabler's theory, (ii) technological enabler's theory and (iii) social enabler's theory. It was agreed that if the use of learning scenarios to represent stimulated applications within the WBS-LS were going to be incorporated then the static/animated models and scenes needed to be realistic and familiar to the learner.

The following summarises the suggested enhancements which resulted from the session:

- With voice communication there will also need to be a visual pointer such as an arrow indicator so the users can point to where they are discussing.
- In order to fulfil learning at your own pace, users will need to be given the capability to manipulate the equipment and replay elements were necessary.
- Because it is intended to be an educational tool, users must be able to test their knowledge and understanding of each element and stage, repeating as many times as they so desire.

4.4 Conceptualisation of the web-based learning system

4.4.1 System requirements

We have established that one of the technological enablers for our concept WBS-LS will be a game engine SDK. Games have always been used in one form or another to help support training and simulation [45]. The term game and game based learning has numerous definitions and interpretations depending on your viewpoint, experience or perception. To the digital learner game based learning involves the use of technological enablers such as personal computers, game consoles, handheld mobile devices or their mobile phones [46]. Therefore the principle design of our WBS-LS will functionally blend technological enablers with cognitive enablers and social enablers based on the cyber psychology theories of (i) engagement, (ii) motivation and (iii) immersion. The following is a list of the WBS-LS main requirements:

- web-based access anywhere, anytime through multiple technological enabler devices.
- library of learning supports, content material and content stimuli.
- library of learning scenarios.
- web-based community of practice.
- web-based interactive discussion forum.
- library of no-complex models.
- library of non-complex scenes both static and animated.
- cognitive stimulation (conceptual, meta-cognitive, procedural and strategic).
- visual stimulation (digital media).
- social stimulation (interpersonal networking).
- bi-lateral voice communication.
- non-linear control options for user.

Digital learners are open to learning appropriate competencies to achieve autonomous control over their educational process and expert educators are seeking the ability to support students in the design and construction of their learning and its environment [31]. The main requirements listed above will provide for a functional WBS-LS that can assists both educators and learners to achieve these objectives.

In terms of the psychological theories of (i) engagement, (ii) motivation, (iii) immersion the literature has closely linked all three when related to the domain of web-based leisure time activities. A person when concentrating on VR activities especially in a video game induced environment can enter what is known as a state of flow. Flow is the state of mind experienced when one is completely absorbed by (immersed), and focused on (engaged and motivated) an activity to the point where all sense of time and external environment is lost. Although initially thought to result from only play and leisure pursuits, Csikszentmihalyi showed that flow can be created through any activity including work [52]. People in a flow state have reported feeling a sense of control over the activity at hand, although this may be more a feeling of being in control as opposed to actually having control [47]. In most flow experiences, it is notable that the activity is sensed as a rewarding, standalone experience and is not undertaken with the expectation of future benefit or reward, thus delineating linkages with intrinsic motivation [52]. Balance between the individual's skill levels and the difficulties of tasks determines the level at which a person will experience flow. The user must perceive that there is a challenge and that they are capable of completing it. Thus every activity can engender flow, but for flow to exist and to be maintained, the balance between the challenge and individual skill must be upheld as the users' skills improve [52].

4.4.2 Functional specification

The main function of our WBS-LS is to provide a VR stimulation system that functionally blends technological, cognitive and social enablers into a seamless operating educational tool to produce higher level problem solving skills for construction engineering students. A decomposition of the functions to be fulfilled by the prototype system is mapped out in Figure 4.10. The main functions are divided up into four main areas as follows:

- ***The technological software enabler functions***, which mainly are game engine SDK functions to enable the creation of design, modelling, scaling, scene addition, adding of hit boxes and creation of computer scripts (Figure 4.11).
- ***The technological hardware enabler functions,*** which are digital functions to enable the use of photographs, digital recordings. Web-based functions to enable the use of multiple devices to connect to the WBS-LS and enable networking connections and operational controls (Figure 4.12).
- ***The cognitive enabler functions***, which are scenario driven task-based problem solving functions to enable activation of cognitive physiological responses. Learning supports, material and stimuli functions to enable cognitive response patterns (Figure 4.13).
- ***The social enabler functions,*** which are mainly networking functions to enable community of practice, discussion forum, interpersonal networking, collaborative learning, peer assessment, contents personalisation and individualism (Figure 4.14).

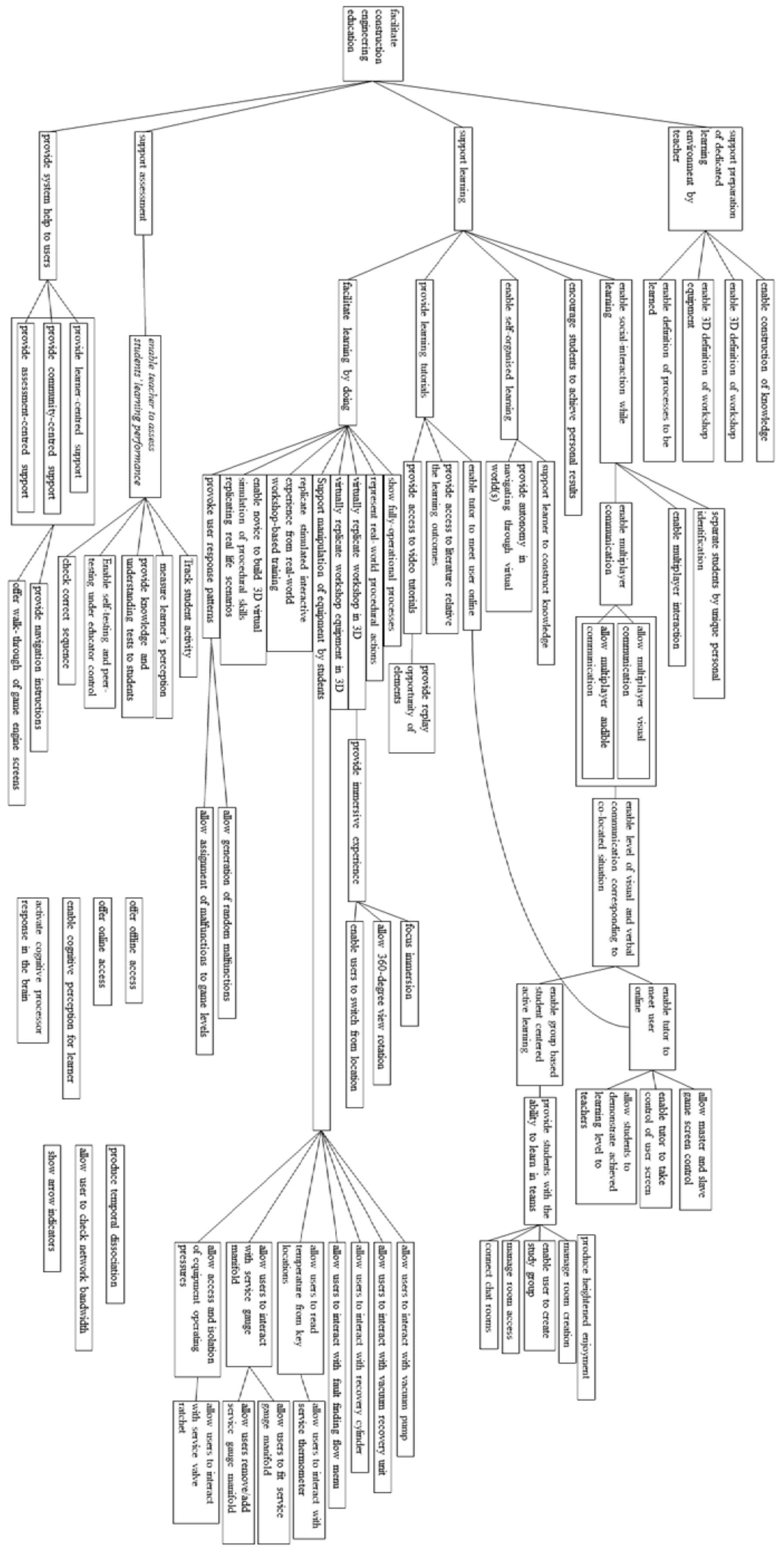

Figure 4.10: Conceptual design for prototype system functionality

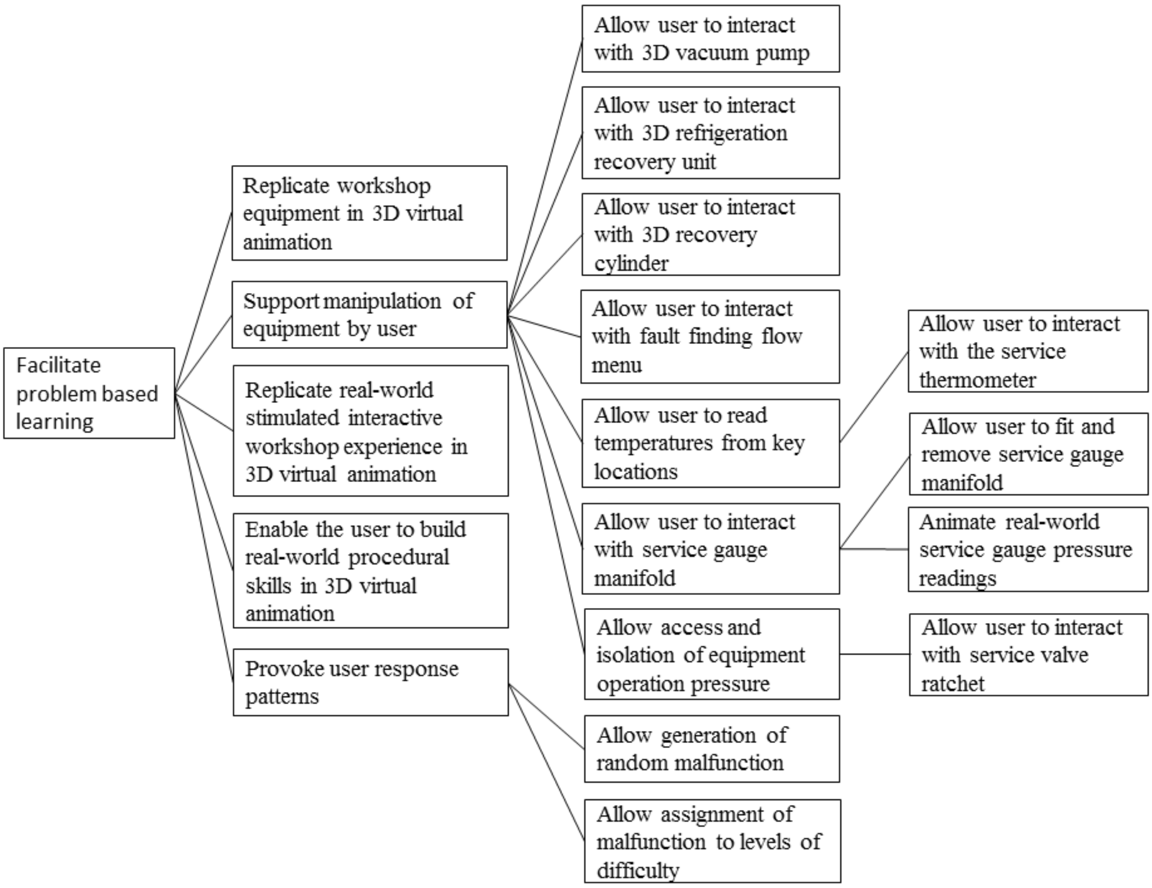

Figure 4.11: The result of the conceptual design of the technological enabler functions of the WBS-LS SDK

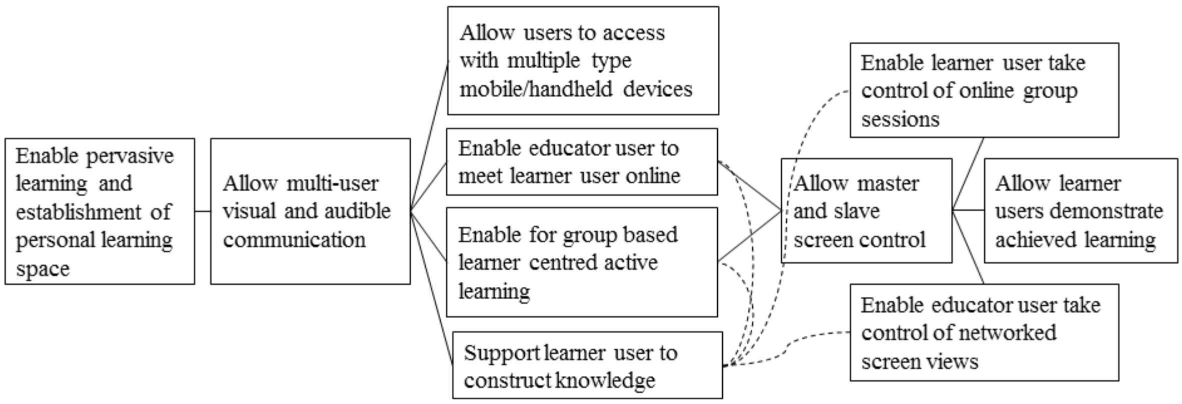

Figure 4.12: The result of the conceptual design of the technological hardware enabler functions of the WBS-LS SDK

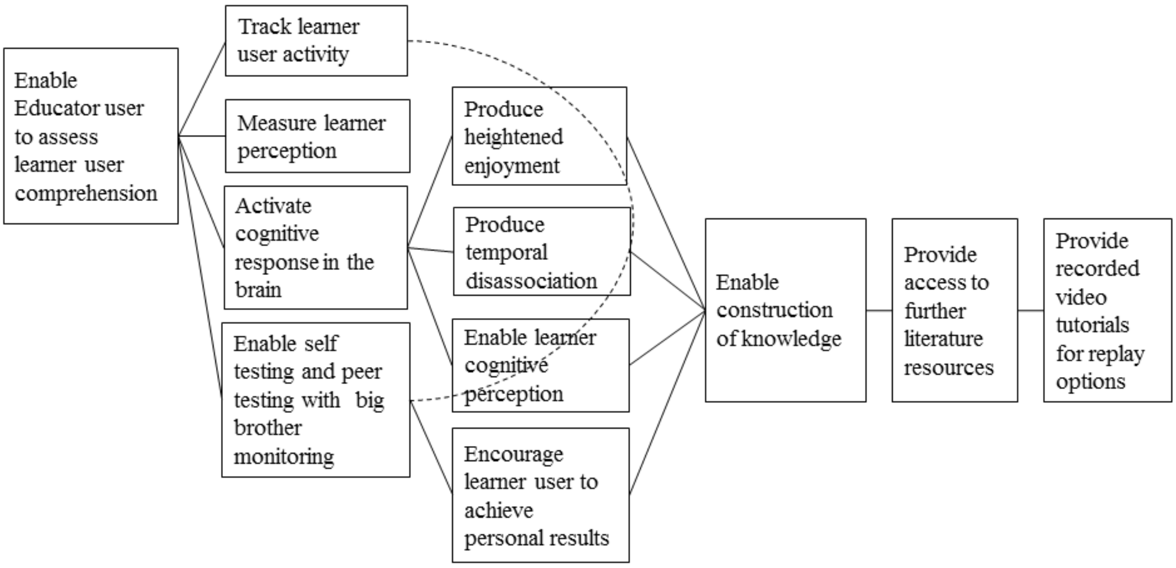

Figure 4.13: The result of the conceptual design of the cognitive enabler functions of the WBS-LS SDK

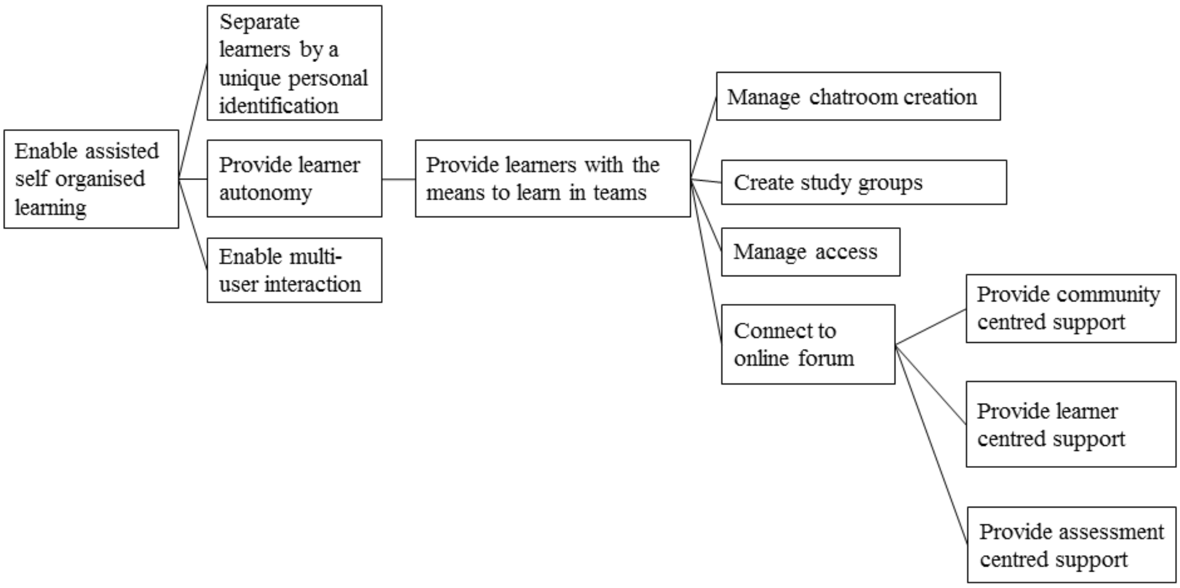

Figure 4.14: The result of the conceptual design of the social enabler functions of the WBS-LS SDK

4.4.3 Architecture specification

The upper part of Figure 4.15 provides a high level view on the architecture specification. The architecture includes: (i) a website management module, (ii) interface components database module, (iii) network manager module, and (iv) a user activity database module for feedback and monitoring. The system also incorporates: (v) a social-enabled interactivity facility, which does not function as a module. The main functions are as follows:

- The website management module is responsible for resource information storage and distribution. The interface components database module takes care of handling media materials, such as video tutorials, lecture notes, etc.

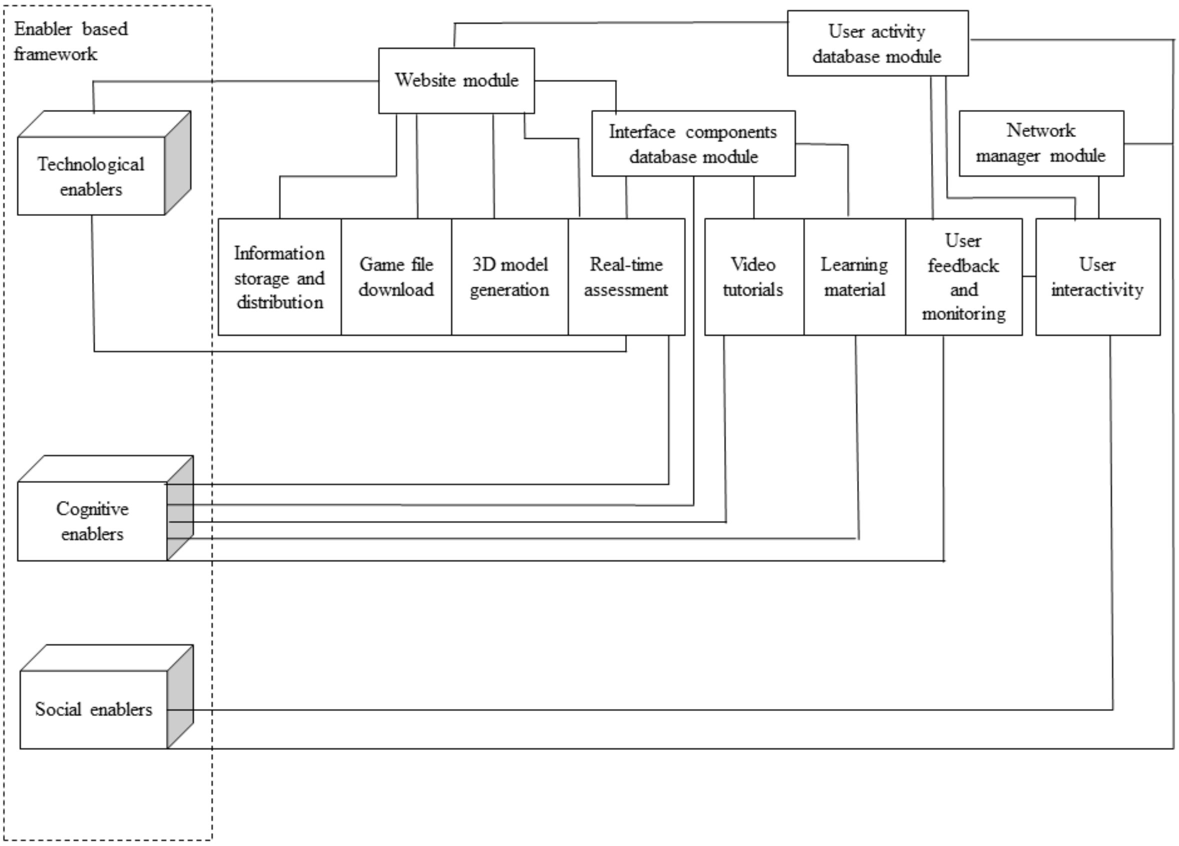

Figure 4.15: High level view of the conceptual architecture of the prototype system

- The network manager module deals with real time interaction and assessment. It does this by knowing which users are online and informs other users who are active at any given point in time. It also provides users with information about their individual connectivity bandwidth. The network manager module provides functions over the network, such as menu or camera switch activities by users within the network.
- The user activity database module collects and stores user's personal identification data, and sends and receives information about the user's activities from the website platform to the web-host, and vice versa.

As shown in Figure 4.15, there are specific structural and functional relationships between the modules. For example, the website module consists of hypertext mark-up language (html) files or web scripts that allow the users to view all files written in various formats, as web browser views. Figure 4.15 also shows that the website module is the hub, where files are sent to, or come from, via other modules in the system.

4.4.4 Website management module

The conceptual design has: (i) a 3D interactive learning application, (ii) web-based virtual reality (VR) learning scenario's that mirror real world actions both in synchronous and asynchronous mode, (iii) bi-lateral communication means, (iv) formative and summative assessment and (v) learning materials which directly relate to VR simulator objects/models [48]. Figure 4.16 presents the activity steps that need to take place to develop the prototype website information pages and simulated learning scenario materials. The bottom half of Figure 4.16 shows the activities to model mechanical refrigeration training equipment which

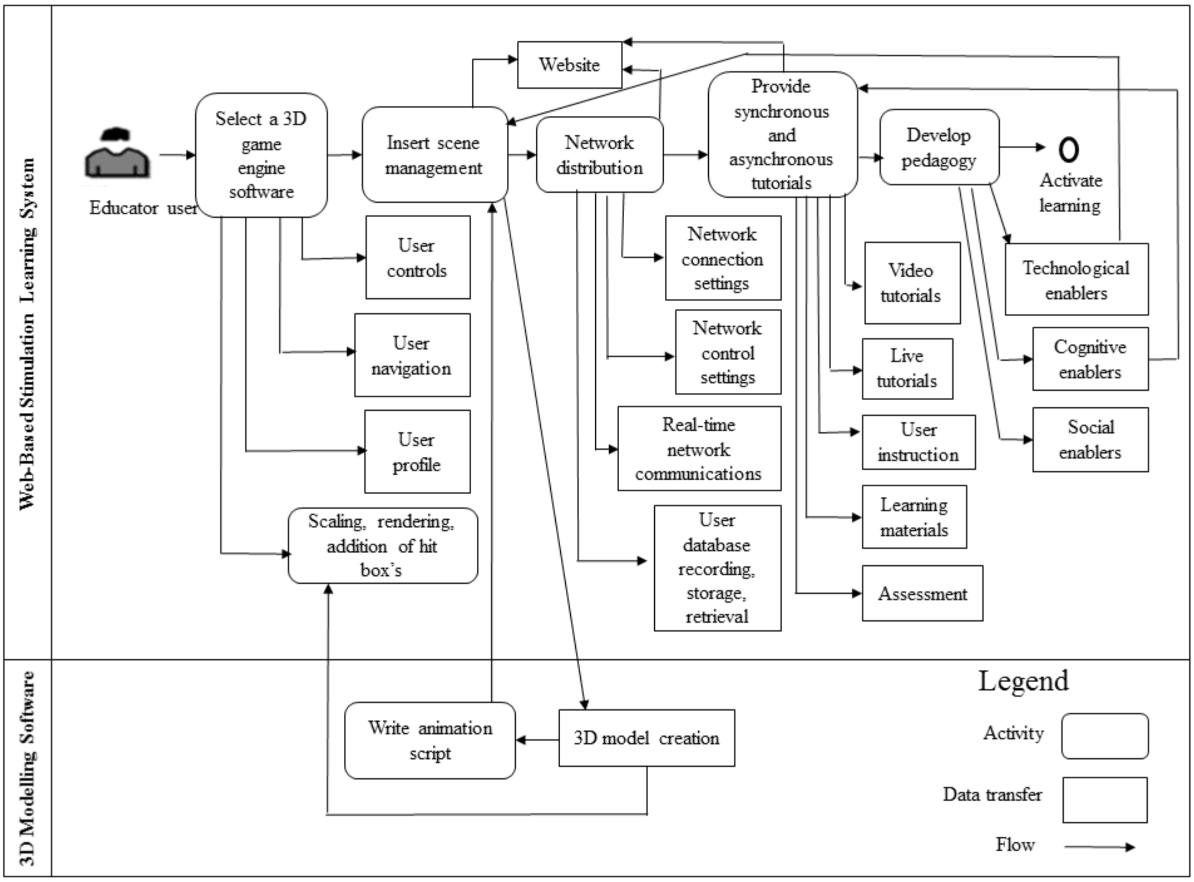

Figure 4.16: The activities required to build the prototype website

duplicates the functionality of the real world training laboratory. This is built using existing scripting available from open source game engine software and importing 3D models developed in compatible open source 3D modelling software. The top half of Figure 4.16 shows how the 3D modelling packages that is finally selected must be compatible with the selected game engine software package. The top half of Figure 4.16 also illustrates the activities required to create the prototype interface design, GUI menu and operation specifications.

4.4.5 Interface components module

Figure 4.17 depicts the conceptual layout of the interface components module. This module was designed to track the interface activities of individual users and to send the updated information to the web host for storage each time a user logs out of the website. When the user logs back on, using their unique username and password, the web host will send the most up to date user interface activity information to the prototype WBS-LS website. Typical information stored for individual learners include (i) number of questions/tasks attempted, (ii) last question/task attempted and (iii) the length of time spend on each question/task.

The conceptual design to manage the user activity database uses an information stream processing service via a relational database management system (RDBMS). Put simply the service takes structured query language (SQL) files held in the RDBMS and sends them as HTML files to the website. Figure 4.18 outlines the conceptual RDBMS architecture for the

prototype and highlights how this design can enable the prototype RDBMS to (i) supply, (ii) store and (iii) manage the relevant files over the network thus ensuring the learner commands are reflected accurately. RDBMS is a proven method that provides for networking and plays an instrumental role for the network management of web-based systems.

4.4.6 Network manager module

In the context of the refrigeration engineering learning module the conceptual design functions of the network management system need to be such that it; (i) enables users to exchange high bandwidth graphic rich data and (ii) connects with communities of practice [49]. The network management module enables users with limited hardware computing capabilities to not need large processors for access and interaction with the WBS-LS [50].

Computer networks and communication systems have increased in scope and heterogeneity in the past number of years [51]. With more cost effective supply of bandwidth comes an increase in possible applications of computer networks and communication systems [50]. The conceptual design of the network management module for our prototype has incorporated the use of cloud computing technologies to allow both educator and learner users to interact with real time tutorials within the virtual learning space.

4.4.7 Preparation for prototyping

The next phase is to use the conceptual designs to build a working prototype. The prototype must prove that the designs do in fact increase the possibilities of engaging students in complex problem-solving. The process will begin by identifying learner discourse that takes place in the real world setting. We will then use the blended enabler framework to construct numerous virtual alternate scenarios from these real life operations and events (i.e. list the basic elements of the system or show operation process) and then integrating the context of those scenarios into constructing an instructional learning and teaching student centre approach that assists dislocated learners achieve the module learning outcomes. To develop scenario learning applications we will use the recorded inputs of the focus group of experts which emanated from the discussion and dialogue. It is equally important in the preparation for the prototype to pay attention to the fact that some of the improvements in human learning abilities are results of numerous technological advances [51]. On the other hand it must also be noted that in some cases it is the advances in technology that have created new problems for the design of learning means for dis-located learners [51].

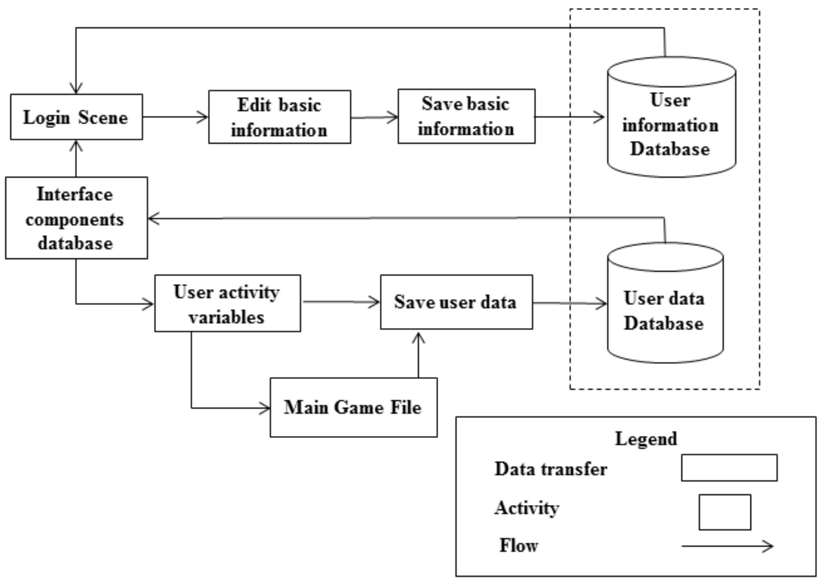

Figure 4.17: Conceptual design of the interface layout of the WBS-LS prototype

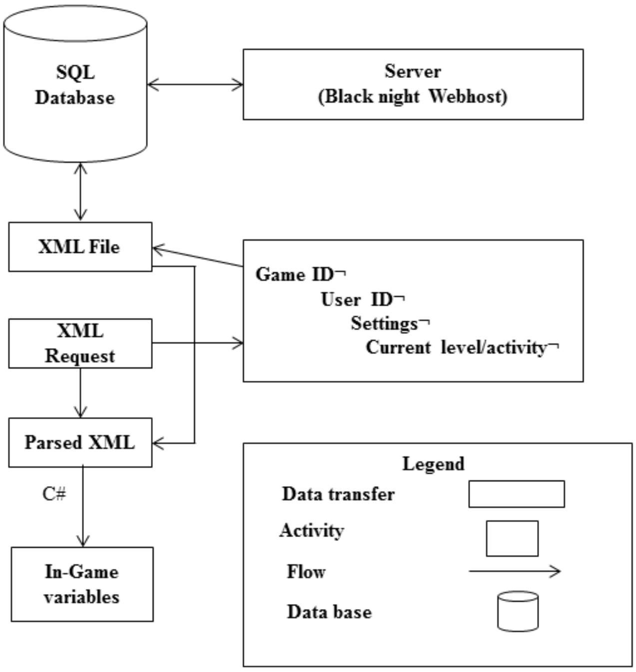

Figure 4.18: Conceptual architecture for networking with relational database management system

The conceptual framework of the proposed novel system was to provide a stimulating learning experience for dislocated digital learners, who are seen as individuals with different perceptions and expectations. In addition to functionally integrating technological, cognitive and social enablers, the system was required to encapsulate what can be called the principles of cyber psychology. The evaluation of the focus group discussions showed that the first results are promising, but attention must be given to implementation details such as real-time content management, fluency of learners' interaction with the system, adaptation to the individual leaner needs, and the depths of engagement of the learners in the highly socialised learning process. These were further considered in the fully-fledged full-scale prototyping of the system. The chapters to follow will focus not only on the prototype-level implementation of the system, but also on the study of its impacts and the increase of efficiency in distributed construction engineering education.

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Chapter 5

Research cycle 4: Realisation and pilot testing of the prototype

5.3 Introduction

5.1.1 Objective of the resource integration

The objective of the explorative part of this research cycle is to extend the knowledge that was used for conceptualisation in Chapter Four with knowledge about the resources and methods of prototyping the proposed system. This process obviously involves activities for detailing the developed system. Figure 5.1 shows the generic workflow which identifies the major steps that were taken to build a working prototype for pilot testing.

5.1.2 Research approach

The initial approach was to capture the real world environment actions and interactions of construction engineering learners gaining practical skills knowledge, (with special attention to

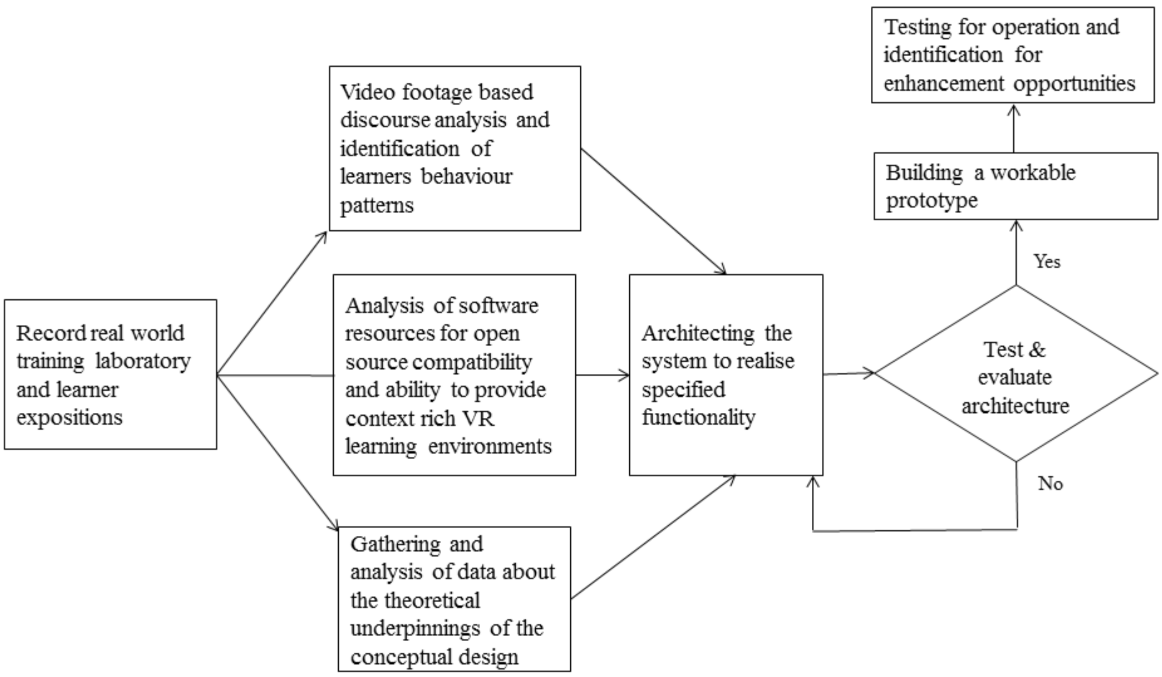


Figure 5.1: Generic workflow of building a working prototype

peer to peer and educator to learner relationships) in refrigeration equipment maintenance and to replicate these expositions in a context rich VR environment. Therefore the first step was to set up a qualitative observational research experiment [1]. As a preparation we sought the permission of learners to place a digital camera in the corner of the refrigeration skills teaching laboratory (located at the Dublin Institute of Technology in Ireland). The primary researcher was the educator during this recording and therefore his role was observer participant. In keeping with the tradition of discourse analysis we studied the digital video footage and examined the way knowledge was produced as a result of the multiple expositions that took place in the real world learning environment [1]. Using this approach we identified the specific patterns of behaviour of learners and used these patterns to design various VR learning scenarios. The next step was to identify the software that could be used to produce a context rich VR environment capable of reproducing the observed discourse and to facilitate the reproduction of equivalent behaviour patterns for dis-located learners.

Because it was our intention to replicate the identified learning patterns and expositions in a context rich VR environment, we were required to build a limited working prototype. In order to achieve this aim we needed to identify an open source or reasonably priced simulation software package. This software package was supposed to be compatible with the latest (currently in use) screen-based hardware devices accessible to typically low income (student) budgets. Finally, the software was also supposed to have a programing interface that allowed the non-computer science programmer to exploit computer programmed functions. At selecting the most appropriate software we relied on the knowledge published in the related literature. There were many software products reported in Chapter Two which were in the main defined as either 3D modelling or game engine packages. These software packages proved they had the potential to meet our requirements. To find a best match we conducted an analyses of their capacity for building the first version of our working prototype. In addition to looking at these software packages for VR modelling we also observed the screen-based camera views provided. We then cross referenced these views with the digital recorded footage. The purpose of this exercise was to identify the key components and the limitations that could be cause for concern when restricted to a fixed flat screen camera.

To test the working prototype we used a focus group session as a qualitative approach to gather data about the correctness of the theoretical underpinnings. The focus group session involved subject matter experts who were asked to express their opinions and expertise about (i) 3D virtual models as realistic representations of real world content, (ii) if the VR environment provides sufficient visual and audible communications means for dis-located expositions and (iii) if there is potential for the VR environment to become the means of an immersive and pervasive learning system. The end results obtained during the focus group session were used to formulate a number of conceptual enhancements for the second build of our VR-based learning system prior to its implementation and application.

5.1.3 Identified challenges of doing this research

One of the main challenges was finding and selecting open source (unrestricted) software that could provide the development tools to build a visual and functional learning environment for dis-located learners. In addition we were also challenged to find open source software resources that could assist us as novice developers and provide a simplified means for rapid development of data (graphics, sound, and physics). In general the learning curve requirements for programming (as a novice) were steep and for some of these software packages the level of digital literacy required were beyond our level of digital competences.

As previously stated, Chapter Two provided a number of case studies, which demonstrated the main differences between the various software packages that are classed as 'game engines' or '3D modelling' software. Our main challenge was to explore each package to determine if our level of digital literacy was sufficient to realise the software capacity and build a working prototype. The open source software packages we tested are listed below with a brief note of the challenges they presented to us.

Sketchup™ was the first modelling tool we used to convert 2D generic CAD graphic entities to 3D models. As novice programmers we found that we were very limited to what we could achieve with this package. From our perspective it was too closed off to us to figure out how to utilise customisable algorithms or to have full control over what we created within the software.

Unreal editor™ could have fulfilled our needs except for the fact that it requires high end hardware devices (expensive to purchase) to run and maintain its highly sophisticated graphics. In other words, we found it to have compatibility issues for mobile and cross platform hardware devices as the high end rendering, meshing lighting effects and texture has been developed to such a level of sophistication it requires the hardware device to have an equally sophisticated high quality graphics card. Such hardware devices tend to be expensive and outside the spending budget of our target learners (students).

Flash™ was originally developed to build 2D games with animation. The latest version offers limited 3D functions which was not sophisticated enough to meet our needs.

Blender™ offers low quality game engine functionality as highlighted in Chapter Two. Some features were unstable and not reliable while other features such as its 3D modelling tools are highly developed and superior to most of other software packages we tested. This is due to its editing and creation tools. In other words, this package compromised the development of the physics engine and collision detection and concentrated on providing a more sophisticated rendering engine for 2D and 3D graphics creation, modelling and editing.

Unity™ presented us with a high level of support through its tutorial and community of practice online forums. However this package has limited 3D modelling features. The main challenge it presented us with was the fact that the complex 3D models we require could not be modelled within the unity package. On the other hand to overcome this challenge, Unity software provided what we refer to as a development pipeline for similar packages (void of commercially sensitive compatibility issues). This meant that there was an option to use the strengths of Unity as a sophisticated game/physics engine software and to substitute its weakness (as a 3D modelling software for example) with alternative compatible software.

5.2 Architecting and specific resources

5.2.1 Introduction

As a direct result of encountering the above challenges our focus changed. Instead of considering a standalone software package to build and test a working prototype, we considered how to use the best features from multiple software packages. When we use the term 'engine'

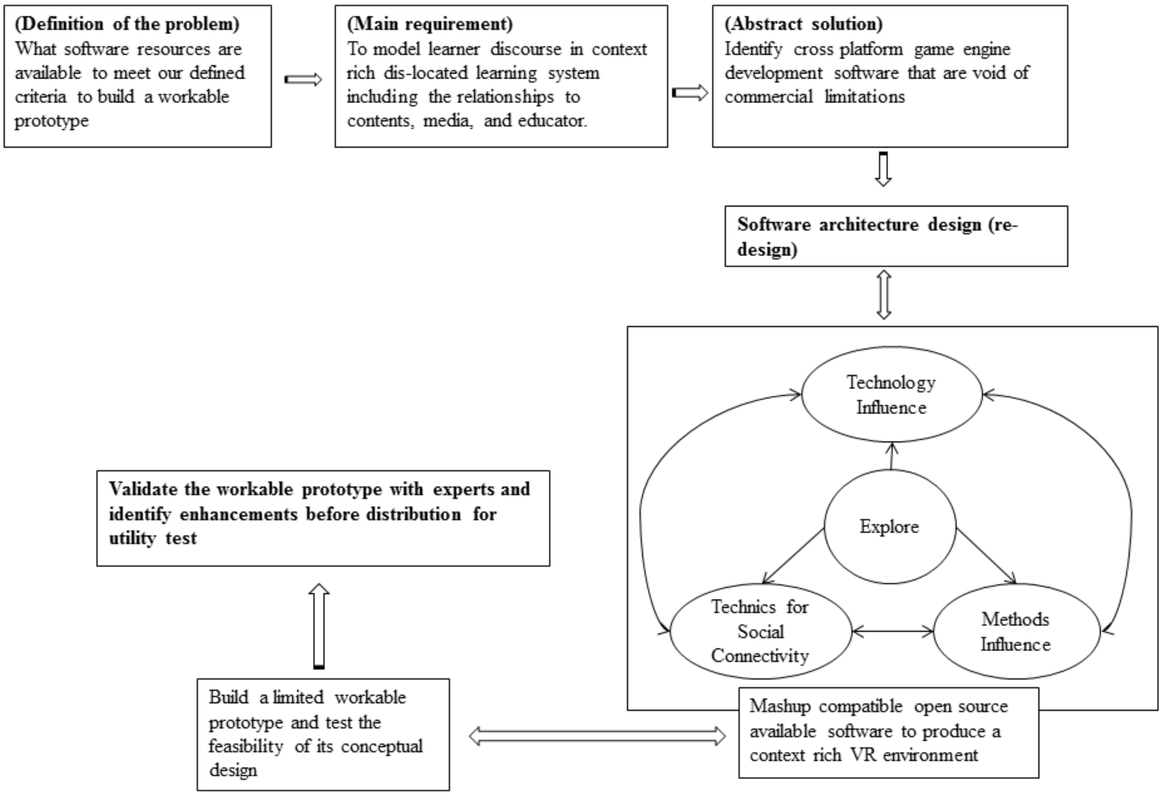


Figure 5.2: Workflow for software resource selection to build the working prototype

we are referring to the piece of software which has programmed algorithms to complete function. For example the rendering engine in Unity functions to generate graphics using ray cast and rasterization algorithms. Game engines are adaptable to any programming language (Java, C++, C#), the structural difference of each language provides different levels of access to varied functions [2]. Figure 5.2 casts light on the main elements of the workflow that have been implemented to find useful multiple resources and to build a functional context rich VR working prototype.

5.2.2 Architecture of the learning system

Figure 5.3 illustrates the basic architecture of the web-based stimulated learning system (WBS-LS). Unity was selected as the main software package because it provided a wide range of programming functions and is compatible with multiple software both commercial and open

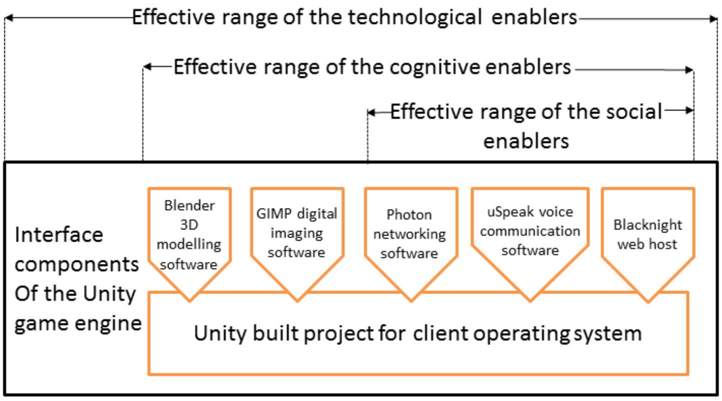


Figure 5.3: Software architecture for WBS-LS

source. For example, Unity incorporated functions to import 3D objects built in Blender. In addition to import functions Unity also provided a 'trigger' algorithm function which enabled none unity graphical models to function in a Unity controlled environment. Because of such functions programmers have the option to model 3D graphic objects and include intelligence (such as animation) using none Unity 3D modelling packages such as Blender. Once imported from Blender to Unity these objects become a Unity asset keeping their original form and intelligences but recognised as a Unity object for compatibility function.

5.2.3 Game engine software

The game engine runs in real time which means lighting, animation and textures react to player movement or object functions. The game engine software functions are initiated by the human user's controls and interactions (via their hardware device). The game engine software provided, for the programmer, the capacity to mimic functions, actions and interactions identified from the discourse analysis of our video footage. The game engine also made it possible for dis-located learners to access images, animations and videos and to control the designed functions over the internet. Effectively the game engine provided a programmable ('exe', 'Android') file that was shareable for download to individual hardware devices.

5.2.4 3D modelling software resource

Blender was tested and chosen as the 3D modelling software resource for the working prototype of WBS-LS. As stated previously this package provides a 3D editing tool/modelling suite of algorithms. Within these algorithm packages are generic template objects to enable the creation of organic curve type shapes. The programmed algorithms do not apply restrictive rules for moving or editing meshes and 3D graphical models. As already stated this software is compatibility with Unity. In fact Unity actually provides the programmer with an option to save Blender models (learning objects) and graphical entities as assets for reuse over and over ('prefab library object'). A saved 'prefab library object' includes the mesh object, the material, the transform and the collider. As depicted in Figure 5.4, the models are initially developed by using the 3D modelling software algorithms. Once the Blender model/graphical entity is stored in Unity as a 'prefab library object' the programmer can start the texture and image tiling sequence required to make the VR prefab library object more visually acceptable as a real world object.

5.2.5 Digital imaging software resource

GIMP™ is a digital image manipulation software. It provided the programmer with the tools to create personalised texturing files (referred to as assets once exported to Unity). The GIMP

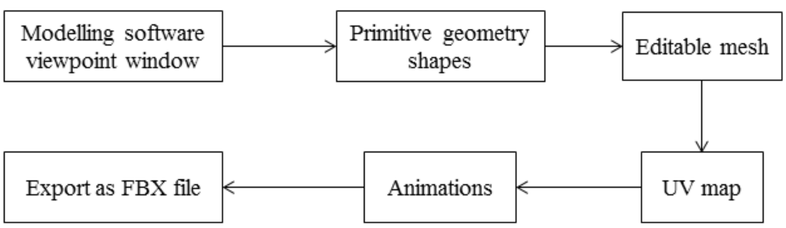


Figure 5.4: Workflow of 3D modelling

edit functions enabled the use of specific (real world training laboratory photos) images to be used to create asset files for MIP (math interpolation) mapping and texturing. GIMP was also the software resource used to size images for tiling and mapping of the 3D graphic entities and models. Because of algorithm functions such as MIP mapping, tiling and zoom screen, it is important that the graphical entities of the VR environment remain to scale and of visual quality. GIMP provided the developer with the ability to segment full images down to manageable squares (iterations). Each iteration image is programmed to be scaled down to half its original size during zoom out function or vice versa and still retain visual quality and scale.

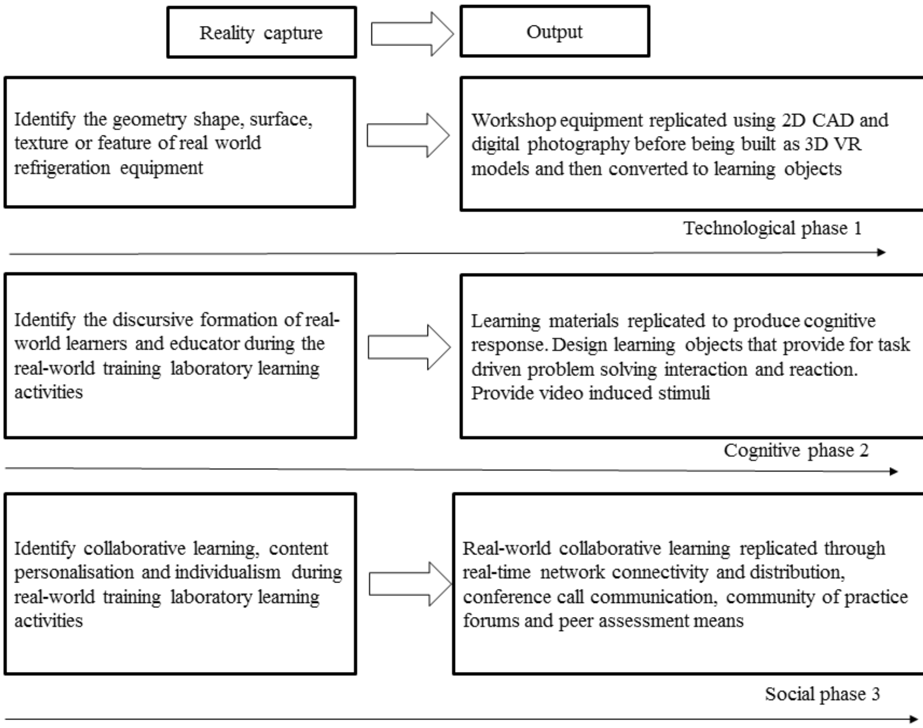


Figure 5.5: Incremental phases for building the working prototype

5.2.6 Networking software resource

The chosen network management software resource is Unity Phonton™. This offers a client-to-server architecture using 'globalised cloud' servers. Unity 3D offers a 'networked peer to peer function' while Unity Photon offers 'room based multiplayer' function via a local (to each networked hardware device) cloud server. This real time networking communication package includes information about cursor movement, who (players) is present in the networked room, who is available online to join the networked room and other features such as multi-screen control of the networked hardware devices.

5.2.7 Voice communication software resource

The voice communication software resource used in system development is uSpeak™. This software was compatible with Unity Photon and the Unity-built VR environment. This voice communication software package used adaptive differential pulse-code modulation (ADPCM) to keep the bandwidth to a minimum for optimal real time networking efficiency.

5.2.8 Web-hosting software resource

Blacknight Solutions™ is the web hosting software resource we used to develop and store the web site content of WBS-LS. The service provided is affordable and includes a dependable after sale customer service backup. The other services offered include the provision of services to build personalised URL website domain and content using their prebuilt web pages. This platform and correspondent PHP files are compatible with Unity 3D.

5.3 Constituents and realisation of the system

5.3.1 Modelling real life laboratory environment

Figure 5.5 shows how the observational research data was incorporated into the conceptual design and used to incrementally build the VR refrigeration maintenance training laboratory. Essentially the process to model the real world refrigeration training laboratory as a VR

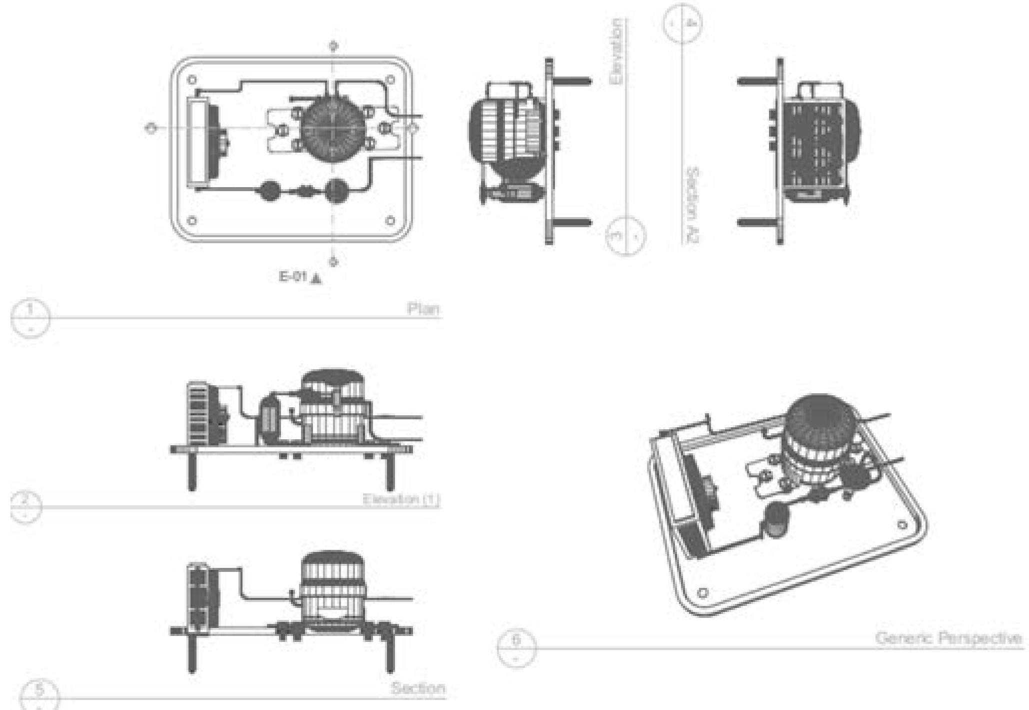
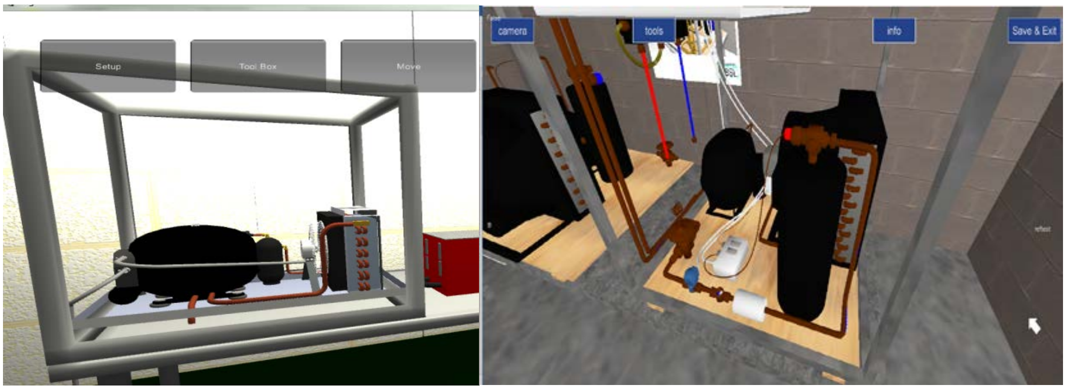


Figure 5.6: Creation of models using generic 3D CAD

equivalent took place over three phases (i) technological, (ii) cognitive and (iii) social.



a b

Figure 5.7. Conversion between representations: (a) 2D CAD entity converted to a 3D model, (b) 3D graphical object modelled in Blender

Phase 1 is the phase of consideration of the technological enablers, which includes the modelling process and the effort required to develop virtual replicas of the refrigeration training equipment. On our first attempt to develop VR versions of the real world refrigeration components, we used a generic 3D-CAD package. These generic CAD software utilise lines, arcs and dimensions to create elements. These elements in turn create graphic entities with no intelligence as shown in Figure 5.6. We then exported these 2 CAD graphic entities into Unity resulting in the recreation of these entities as 3D models (Figure 5.7a). When we tested the 3D models in Unity and began the process of adding intelligence (such as animation and colliders), we discovered the graphical polygon size for these graphical entities was excessive especially for attempting network connectivity. This led us to revisit the related literature and to look more closely at 3D modelling software. In the end we concluded that Blender as a 3D modelling software packages offered the most effective means of producing VR objects that require high visual effect and low polygon file size (Figure 5.7b).

Included in this phase was the use of the Unity interface to create the VR version of the physical classroom laboratory. The actual classroom itself consisted of four walls, a ceiling, a floor, a door, ceiling lights and a light switch. The VR object of the physical room set the scale for (i) other 3D objects that needed to be introduced to this room, (ii) all real world movement that needed to be replicated within or around this room and (iii) learner user controls and screen-based field of view. Figure 5.8a is a screen shot of the Unity interface for the system

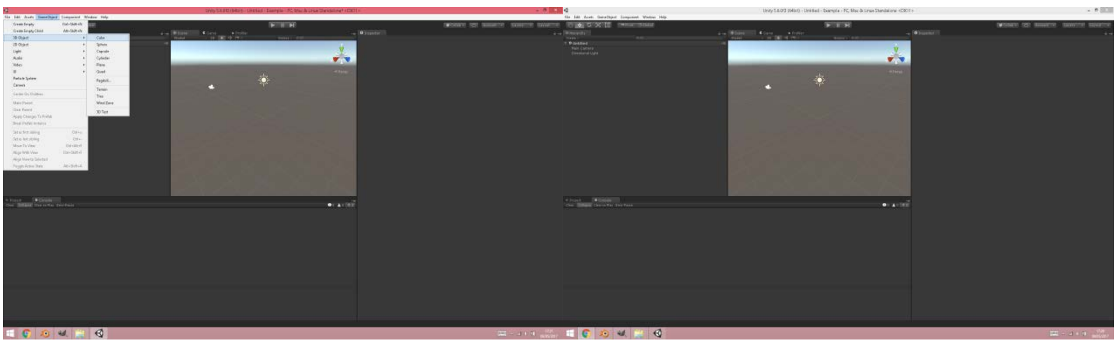


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Figure 5.8: The user interface: (a) Unity's programmers' interface, (b) Unity's programmers' interface menu to create a cube (room shape)

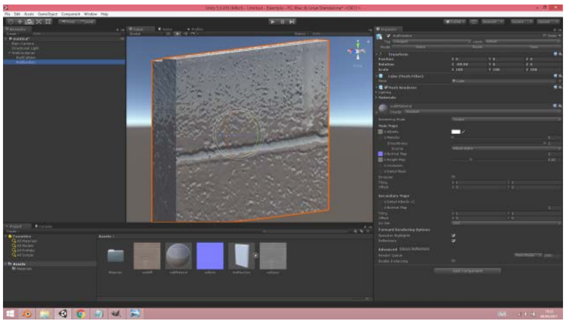

Figure 5.9: Blender model with digital texture exported to the Unity wall placeholder position

programmer. Figure 5.8b illustrates the menu options for creation of the VR laboratory (dimensions and physical characteristics), which in our case happens to have the same characteristics as a standard cube shaped object.

In Unity terms, this cube-shaped object is referred to as a ‘placeholder’. Specifically the cube shape represents the characteristics and dimensions of the real world refrigeration classroom. The term ‘placeholder’ refers to the position and location on the screen (within the VR environment) of each object. For example the room shape occupies the entire screen. On the other hand each VR refrigeration component is placed within the room and occupies specific areas of the room (on the screen). Unity ‘placeholders’ have readymade scripted colliders for physic attributes (‘hit boxes’). The steps of creating a Unity ‘placeholder’ (such as our classroom) are shown in Figure 5.8b. This ‘placeholder’ (cube-like shape) represents the physical proportions of the floor, walls, ceiling, entrance door, light switch, and ceiling lights of the real world classroom. The scaling of the cube is visually proportional to the real world scale of the training classroom.

The cube-shaped ‘placeholder’ also reflects a physical nature, which is provided by the physical frame of the collider. The physical nature means, for instance, that other physical objects represented by geometric shapes cannot pass through the physical boundaries. In other words, just like in the real world, if a ‘placeholder object’ gets into contact with another one, they will collide. The next step of the procedure is to add the VR objects of refrigeration training inside the physical boundaries of the virtual classroom. These objects were first added as placeholders. They were in size and in shape proportional to the equivalent objects in real world. In order to make the arrangement look like as the real world, we used digital

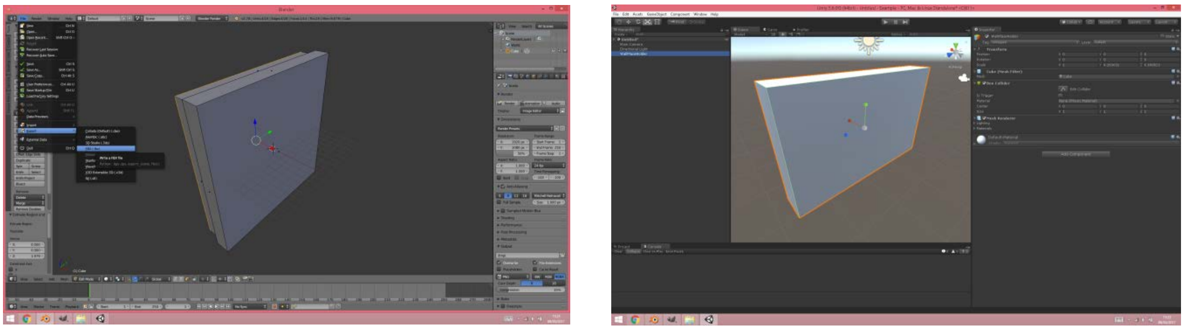

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Figure 5.10: Importing 3D models to Unity: (a) Unity’s place holder for a wall object, (b) Blender’s wall object ready to be exported to Unity

photography to render the walls, floor and ceiling of the cube, as well as of the other refrigeration objects.

Untraviolet (UV) wrapping is also a well-defined feature of Blender. The UV wrapping algorithm of the Blender pastes the digital images onto the surface of the 3D modelled objects. As a reference the system of coordinates of the target objects are used. This way we could map the digital images of the real world items to the 3D virtual objects. Using digital photographs and the Gimp software, we created ‘tile-able’ textures which after having been exported to Blender became part of the Blender asset library (Figure 5.9). For each ‘placeholder’ shape that was created in Unity we modelled a 3D graphical object in Blender. When we exported these objects from Blender to Unity they were saved as ‘prefab assets’ in Unity. Once established as a Unity asset they could be inserted into the matching placeholder shape on screen. Figure 5.10(a) is an image of a Unity ‘placeholder’ that represents the size, shape and screen location for one of the walls for the training classroom. Figure 5.10(b) is the prefab asset of the wall and is placed inside Unity placeholder shape located on the screen.

A key feature of this process was to ensure that each object/model appeared in the right scale on the screen. Figure 5.11(a) and 5.11(b) are screen shots showing examples of when blender objects are visually disproportional to the unity placeholder shape. If an object/model was of a disproportional scale (visually too large or too small) we had to export the asset (the concerned 3D object) back to Blender to make the necessary adjustments. Once the updated 3D object was returned to Unity, the originally stored asset was overwritten and replaced by the new, adjusted-in-proportion object. The reason for not making this correction within Unity was its limited 3D editing and modelling capability. Making such changes using Unity software sometimes led to visual defects.

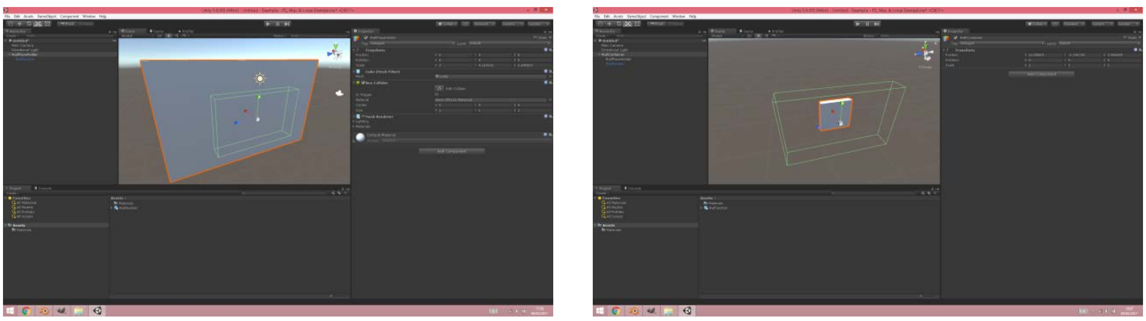

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Figure 5.11: Scaling the imported object in the Unity game engine: (a) Blender’s model of a wall (object is too small), (b) Blender’s model of a wall (object is too big)

```
Ray ray = Camera.main.ScreenPointToRay(Input.mousePosition);
```

This command is to cast a ray directly from the point that the mouse has clicked. The ray will continue in a straight line until it hits something (collider box), or has reached a predetermined set distance.

```
RaycastHit hit;
```

This command confirms the correct collider box for the ray to hit in the 3D space.

```
if (hit.collider.gameObject.tag == "TestBox")
```

The hit is the point in the VR space that the ray was stopped. In the example we gave the collider box a tag identity; 'TestBox'. This enabled us to check we were hitting the desired object and the ray script was functioning. This process continues to check the ray cast script functioned for each of the 3D models.

Figure 5.12: Examples of ray cast scripts with explanations

5.3.2 Modelling learning activities of the real world laboratory

All learning objects were identified from our observational analysis of the video footage. Each learning object was devised from the 3D objects created in Blender then exported to Unity and placed inside the designated unity placeholder as detailed in Sub-section 5.3.1. A number of the 3D objects needed animation to mimic the function of their real world counterparts. The Unity placeholder is a useable object in its own right with its own identity and is used to activate the intelligence function of the 3D object that has been placed inside. For example, we mostly used a ray cast script when we wanted to mimic a functional action. It is the ray cast script that ensures that items such as the mouse cursor appropriately hits the Unity placeholder (collider box). This means that a ray is cast from the screen cursor position as a straight line direct to the collider in the ray path of the cursor. When the path of the ray cast is obstructed by a collider placeholder, the point of collision is returned as information (message) to the original script source (mouse control). The message confirms to the source that the Unity placeholder is the intended collider, and therefore the command for the scripted action can be triggered. Figure 5.12 gives examples of Unity's scripts for ray casting and provides a brief explanation on each code line.

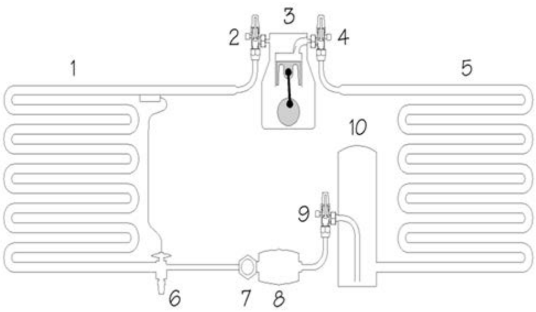
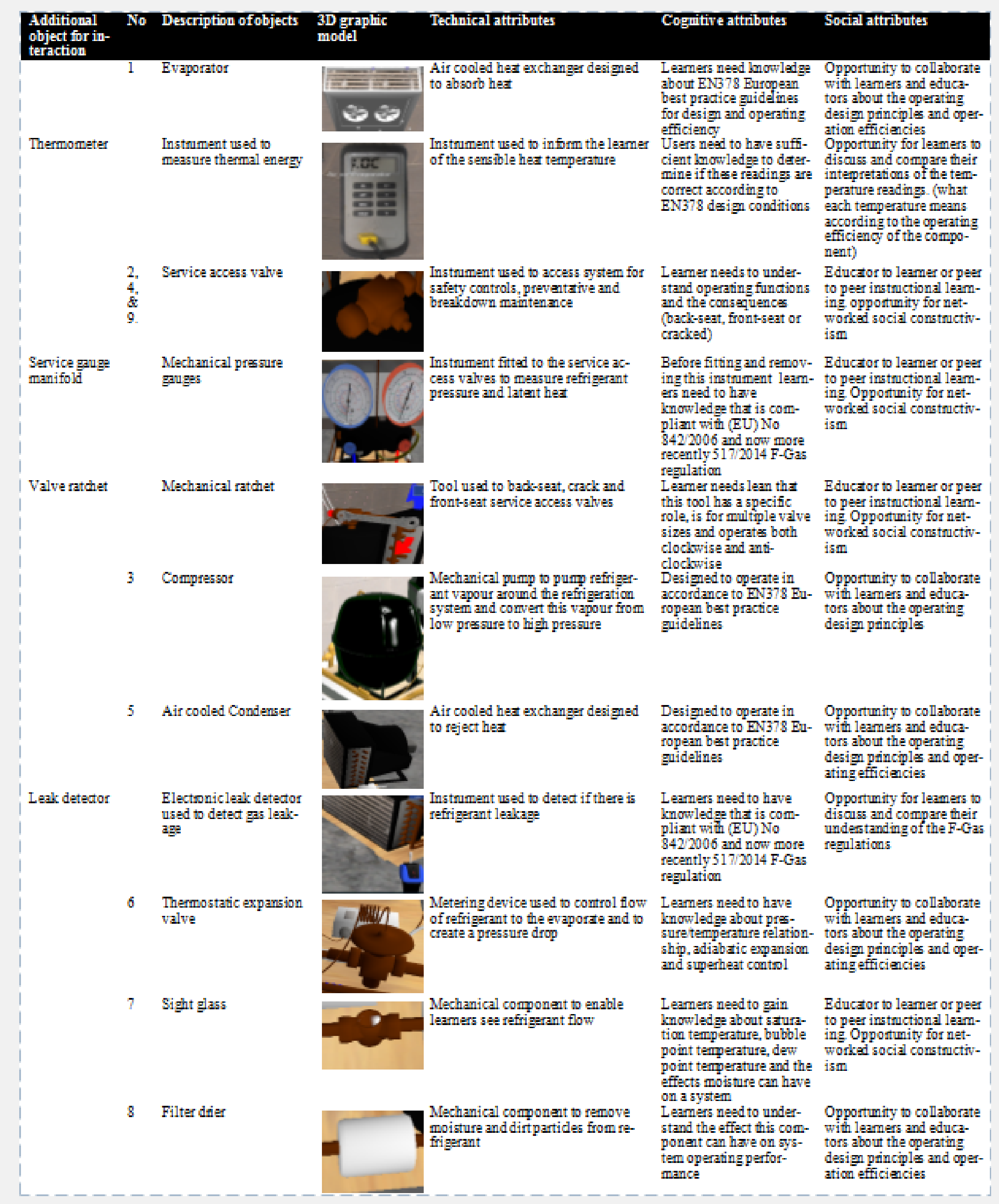


Figure 5.13: Standard schematic drawing of a refrigeration system with components, numbered for reference purposes

Phase 2 is cognitive design, which involves the introduction of the learning material designed to provoke cognitive responses. Part of this process required us to blend the technological enablers with the cognitive enablers to support completing certain tasks. For example, to convert the 3D refrigeration components into interactive and reactive learning objects. Based on our observation concerning task-driven problem solving interactions and reactions that take place in the real world training laboratory, we utilised both Unity and Blender programming scripts for each relevant 3D objects and attempted to mimic the real world equivalent operations. In order to achieve this goal we used a standard schematic drawing of a refrigeration system and numbered each of the refrigeration components that were regarded as learning objects (Figure 5.13). It needed further investigation if a particular object could be reused as a



Additional object for interaction	No	Description of objects	3D graphic model	Technical attributes	Cognitive attributes	Social attributes
	1	Evaporator		Air cooled heat exchanger designed to absorb heat	Learners need knowledge about EN378 European best practice guidelines for design and operating efficiency	Opportunity to collaborate with learners and educators about the operating design principles and operation efficiencies
Thermometer		Instrument used to measure thermal energy		Instrument used to inform the learner of the sensible heat temperature	Users need to have sufficient knowledge to determine if these readings are correct according to EN378 design conditions	Opportunity for learners to discuss and compare their interpretations of the temperature readings. (what each temperature means according to the operating efficiency of the component)
	2, 4, & 9.	Service access valve		Instrument used to access system for safety controls, preventative and breakdown maintenance	Learner needs to understand operating functions and the consequences (back-seat, front-seat or cracked)	Educator to learner or peer to peer instructional learning opportunity for networked social constructivism
Service gauge manifold		Mechanical pressure gauges		Instrument fitted to the service access valves to measure refrigerant pressure and latent heat	Before fitting and removing this instrument learners need to have knowledge that is compliant with (EU) No 842/2006 and now more recently 517/2014 F-Gas regulation	Educator to learner or peer to peer instructional learning. Opportunity for networked social constructivism
Valve ratchet		Mechanical ratchet		Tool used to back-seat, crack and front-seat service access valves	Learner needs lean that this tool has a specific role, is for multiple valve sizes and operates both clockwise and anti-clockwise	Educator to learner or peer to peer instructional learning. Opportunity for networked social constructivism
	3	Compressor		Mechanical pump to pump refrigerant vapour around the refrigeration system and convert this vapour from low pressure to high pressure	Designed to operate in accordance to EN378 European best practice guidelines	Opportunity to collaborate with learners and educators about the operating design principles
	5	Air cooled Condenser		Air cooled heat exchanger designed to reject heat	Designed to operate in accordance to EN378 European best practice guidelines	Opportunity to collaborate with learners and educators about the operating design principles and operating efficiencies
Leak detector		Electronic leak detector used to detect gas leakage		Instrument used to detect if there is refrigerant leakage	Learners need to have knowledge that is compliant with (EU) No 842/2006 and now more recently 517/2014 F-Gas regulation	Opportunity for learners to discuss and compare their understanding of the F-Gas regulations
	6	Thermostatic expansion valve		Metering device used to control flow of refrigerant to the evaporate and to create a pressure drop	Learners need to have knowledge about pressure/temperature relationship, adiabatic expansion and superheat control	Opportunity to collaborate with learners and educators about the operating design principles and operating efficiencies
	7	Sight glass		Mechanical component to enable learners see refrigerant flow	Learners need to gain knowledge about saturation temperature, bubble point temperature, dew point temperature and the effects moisture can have on a system	Educator to learner or peer to peer instructional learning. Opportunity for networked social constructivism
	8	Filter drier		Mechanical component to remove moisture and dirt particles from refrigerant	Learners need to understand the effect this component can have on system operating performance	Opportunity to collaborate with learners and educators about the operating design principles and operation efficiencies

Figure 5.14: Technical, cognitive and social attributes of the refrigeration 3D graphic models

learning object. It was another issue what attributes were needed to describe a 3D object as learning object, and how could it be technically converted to a useful learning object in the VR environment.

After having numbered each of the refrigeration components, the next logical step was to develop a list of attributes with which each of these components contributes to the technical, cognitive and social enabler-driven design framework. Figure 5.14 summarises the used learning objects and their attributes. The learning object design and the contributions of these 3D graphical objects to learning were decided based on the best practices and criteria of refrigeration design. For example, component number 1 (Figure 5.14) was described as an evaporator (air cooled heat exchanger). This component works according to the principle of air temperature differences and vaporisation of the refrigerant gas by latent heat. The best practice guidelines of EN 378 provided information about the criteria to ensure an efficiently operating evaporator. The criteria could be met when the correct air temperature was maintained across the evaporator coil.

Refrigeration design dictates that an efficient temperature difference (ΔT) range is a value between 5 to 10 degrees of a difference. That is, the ‘air on’ temperature (room/cabinet temperature) needs to be between 5 to 10 degrees higher than the ‘air off’ temperature. Therefore, to convert the 3D graphical image of an evaporator to a useful learning object we needed to simulate air on, air off and refrigerant circulating temperatures. We modelled the evaporator object using the technic as described in Sub-section 5.3.1. We then created a placeholder in the VR environment (position on the screen) to represent ‘air on’ to the evaporator and again as described in figure 5.12, we gave it a ‘tag’ name for the ray cast signal to recognise. Introducing tag names means we can use a placeholder detail multiple times, for example the same placeholder detail was copied and moved to a position on the screen that represented ‘air off’. Figure 5.15a is a screen shot showing how the ‘air on’ placeholder tag is positioned in front of the evaporator object. Figure 5.15b is a screen shot of the Unity interface menu illustrating the tag names we provided for each placeholder object.

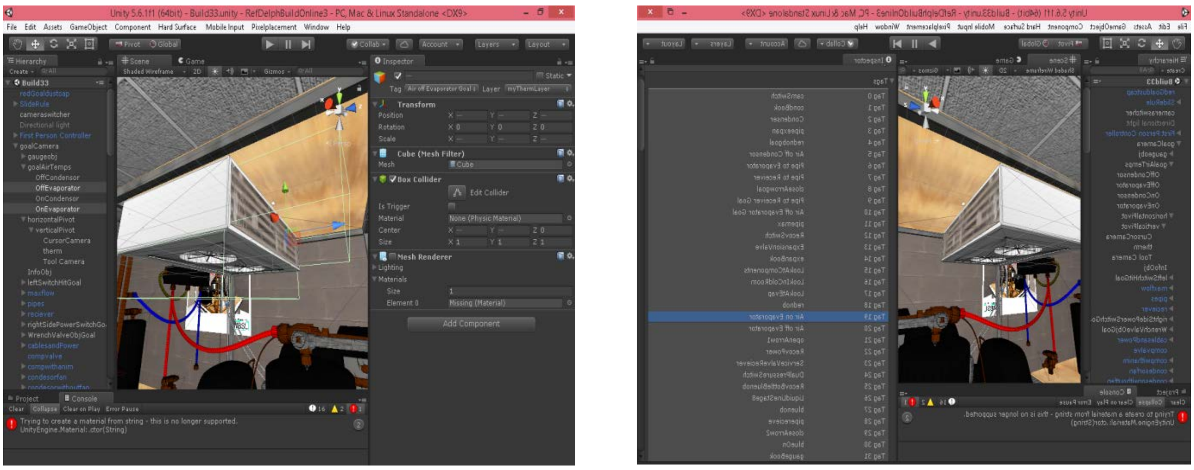


Figure 5.15: Creation of a collider box: (a) location of the ‘air on’ and ‘air off’ placeholders (Unity’s collider box), (b) tag names given to each placeholder object

Figure 5.16: 3D modelled evaporator and thermometer object measuring air on temperature

In the real world training classroom a thermometer is used to measure temperature. Therefore in order to convert the 3D evaporator with its air on and air off placeholder tags, into a useful learning object we introduced a VR thermometer. We then used this thermometer to provide the learner user with temperature readings and relevant feedback messages. Figure 5.16 is a screen shot image of the virtual thermometer. The thermometer commands were written as ray cast script. Figure 5.17 provides an example: Line 227 is the command to cast a ray from the camera position (learner users view point or line of sight) to where the mouse curser is placed. Line 229 is the target object for the ray cast. Line 234 is the command we wrote to check each object that the ray cast comes in contact with and to only return a message when it is the target object. On the occasions when the ray cast is not hitting the target object this line of script commands that no return message is sent back to the thermometer GUI.

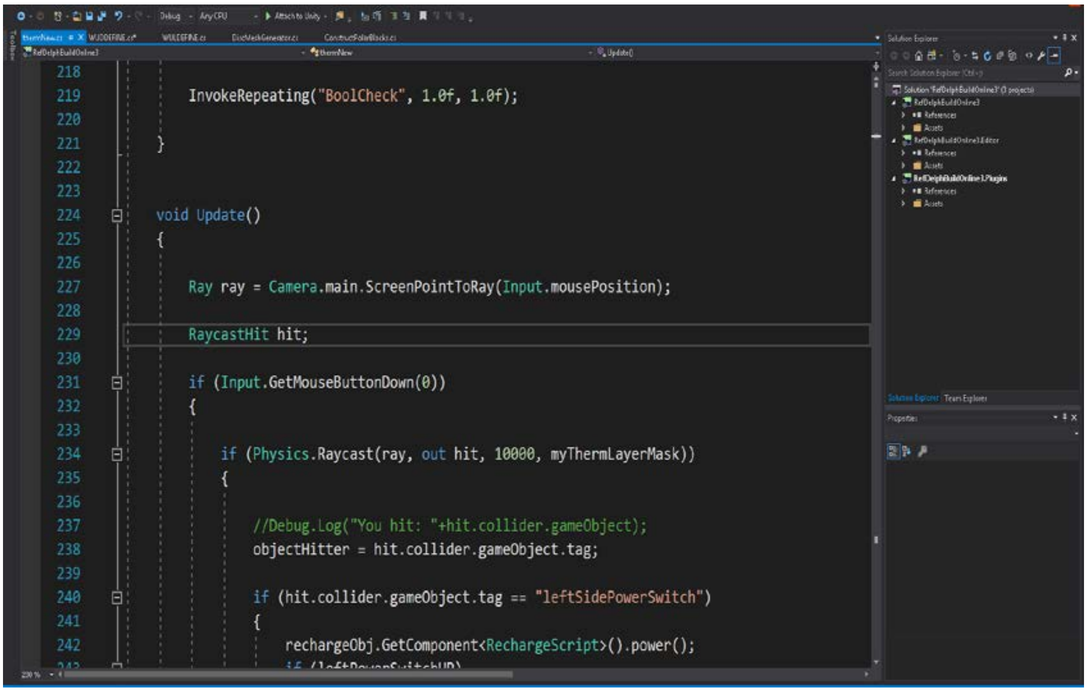


Figure 5.17: Ray cast script to trigger temperature animation sequence

5.3.3 Programming the elements of the real world laboratory

Figure 5.18 depicts the commands we wrote to complete the animation sequence for each specific object that required a temperature displayed. Line 1329 for example, confirms the ray cast has hit an object with the tag name air on evaporator. Line 1331 is the command to trigger the thermometer objects temperature animation sequence and move through the number of frames depicting the values from start temperature to end temperature (expected temperature reading). Once triggered the animation sequence changes frame by frame the digital number on the thermometer display. The second function of this command (line 1331, tagged ThermHit) is to change the information label to the correct tag name (Figure 5.16, the tag name is Air on evaporator and digital display temperature is 1°C).

When creating this ‘ThermHit command we also needed to consider how to develop a script that would change the variables on the screens of the hardware devices that were on the network (internet connected). In summary we needed to provide a command that would check if the master slave screen control function was active (connected online) and operating through the Unity Photon networking software. Our solution is depicted in lines 2330 to 2338 of Figure 5.19. Essentially the command tagged ThermChange was written as a remote procedural call (RPC) command to change the variables displayed on the thermometer GUI of the other devices connected as slave controlled networked devices.

Positioning the VR 3D thermometer object on screen created its own challenges. Once such challenge was that the GUI display (Figure 5.16) remains in a fixed position on the screen while the camera orbit script allows the learner user to move the camera positional view point around in the virtual space. In certain cases, for instance when the orbit camera script is in use, the rendered background changes in colour. This caused us difficulty with ensuring the

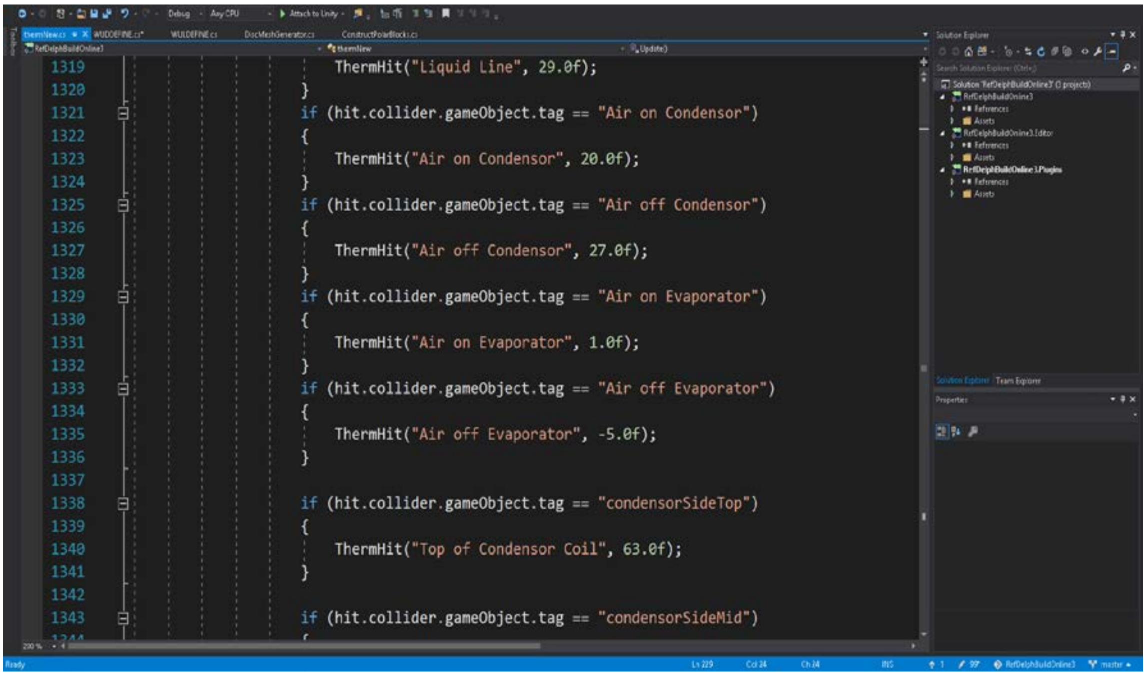


Figure 5.18: Animation commands for each tag object associated with temperature

thermometer information label font was legible on light backgrounds as well as dark background rendered scenes. Figure 5.20 is an example of the variable script declarations we

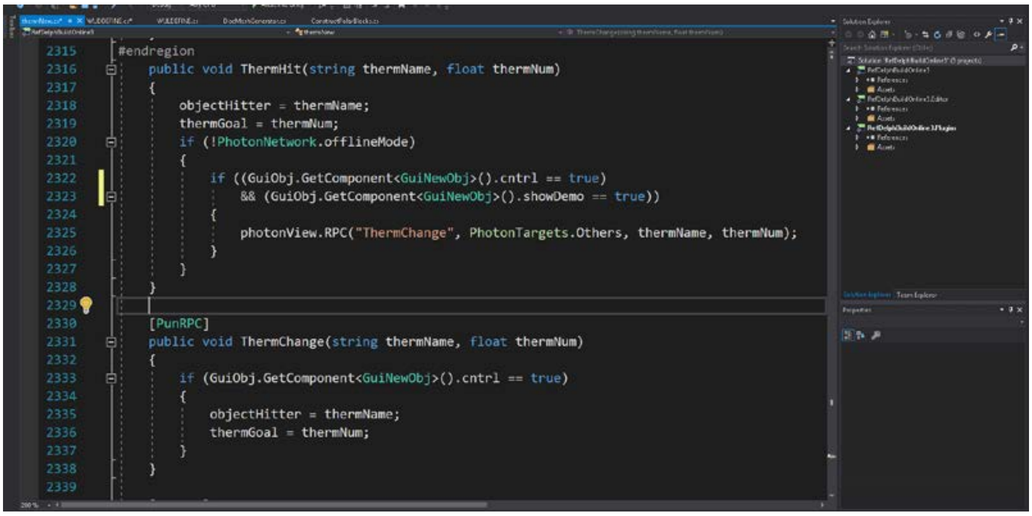


Figure 5.19: Sample of the written RPC commands for networked control

wrote to create separate GUI ‘skin’ interface to hold the required font (colour and format) and ensure the information labels are legible when the rendered background scene changes from dark to light and vice versa. The three declaration scrips are depicted in lines 36 to 38 (Figure 5.21). The first one is the thermometer digital display of temperature (Figure 5.15). The second one is the white font label used to provide the user with feedback information (air on evaporator, Figure 5.16). The third one is the background outline font which is activated when the background rendered texture changes from dark to light thus ensuring that as the camera orbit rotates around the VR space the learner can still read the white font information on display

5.3.4 Visualisation of the elements of the virtual laboratory

The expectation of the learner is to see temperature values that are needed to match with EN378 design criteria as stated above. In order to meet these expectations we inputted a number of variables (lines 40 to 46 in Figure 5.20). We wrote an animation script to enable these variables to change from one set of values to another one. The method used to convert each VR 3D refrigeration component object into a useful learning object resulted in a heavily clustered screen space causing us some difficulties with the accuracy of our ray cast scripts. Figure 5.21

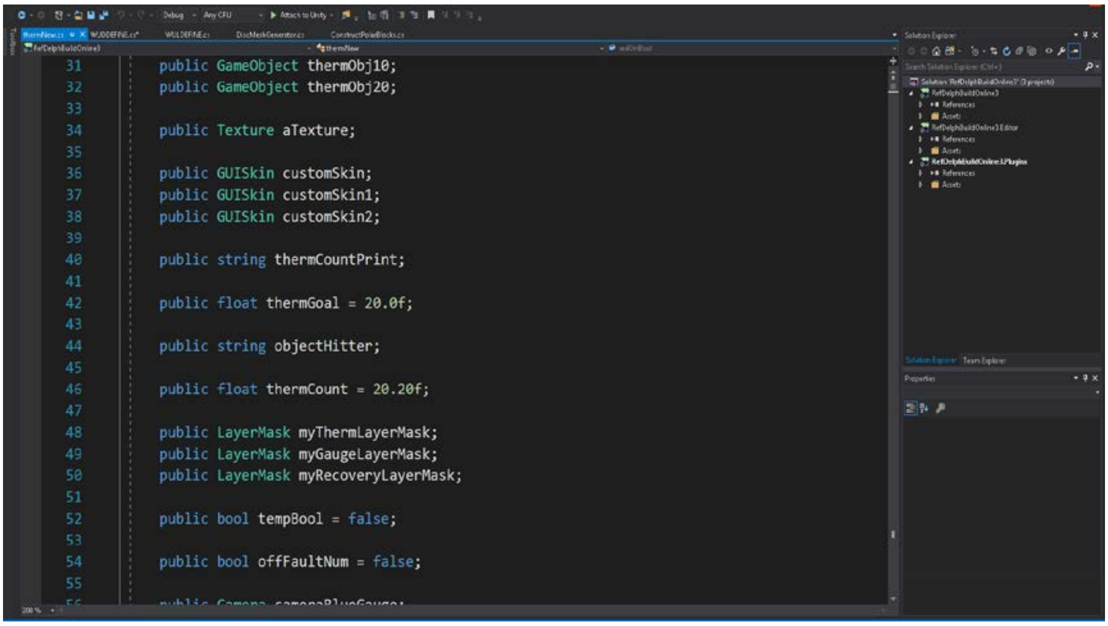


Figure 5.20: Example of Unity script for thermometer display GUI skin

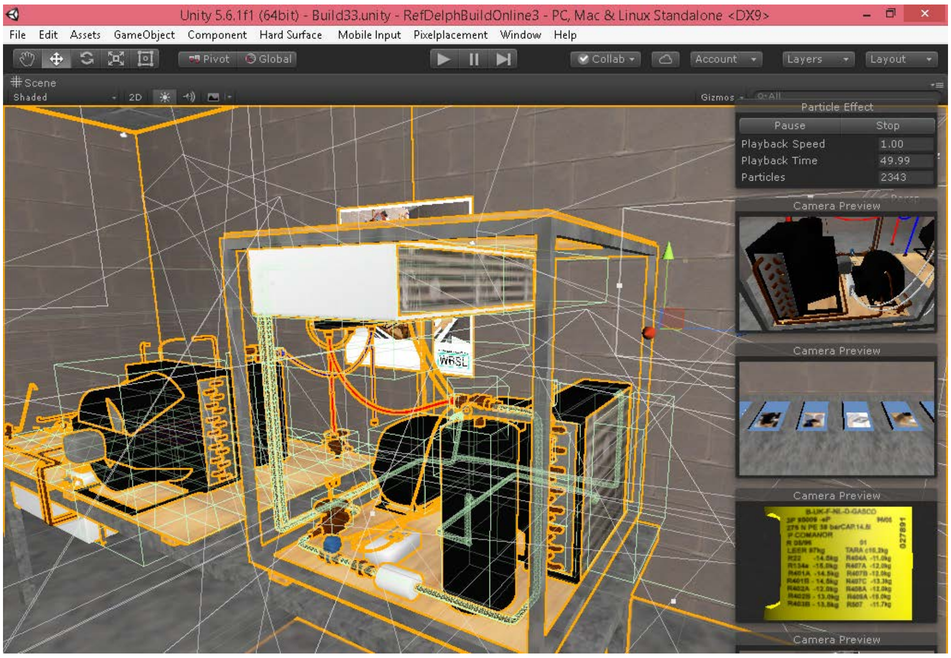


Figure 5.21: Number of objects (hitboxes) within one scene for ray cast signals to hit

illustrates the number of placeholder (collider) shapes in one scene - each with its individual tag name. To ensure higher accuracy of our ray cast signal we used the unity facility of layering. This is a process whereby one can group the similar placeholders into one 'layer mask'. This made the point-and-click of the mouse cursor more manageable and provided better accuracy for ray casting signals to ignore all tags that were outside the designated layer mask.

The learning activities as identified from our observational analysis could only be modelled once we had converted the 3D models to learning objects. To be in line with the modelling technics explained above, we studied the real world learning activities from our observational digital footage and collected a number of digital images for reference. The operating cycle of a refrigeration system was based on the vapour compression principle. This was the situation when refrigerant gas is pumped by the compressor between two heat exchangers. The primary role of these heat exchangers is to absorb and reject heat. There is a metering device fitted to create a pressure drop and control flow of refrigerant. The learning instructions devised for learners concerning the basic training were about enabling learners demonstrate their theoretical understanding of the condition of the refrigerant gas changes as it circulated between the components. This theoretical knowledge is then improved and further advanced before being applied to a real world working system to determine if the operating conditions are in keeping with the vapour compression principles and EN378 best practice guidelines as explained earlier. With this in mind we had to consider additional animation and ray casting script commands needed to enable the learner user to learn while doing and develop higher level problem solving cognitive thinking.

As identified based on our observational data, we listed the specific VR learning objects and their contribution to enabling the completion of the learning activity for each learning instruction. Following the completion of this list, we could afterwards set about writing the necessary animation and ray casting commands to simulate the learning activities. Table 5.1 provides a summary of (i) the learning instructions, (ii) the learning objects needed to complete the instructions, and (iii) the contribution these learning objects made to the learning activity.

Figure 5.22: Zoom camera ray cast activated gauge manifold view

Having formulated the details in Table 5.1 and having completed the necessary script to enable the learning activities take place, we concentrated on the screen view limitations. For example, when a learner needed to read information from the mechanical gauge in the real world training laboratory, they picked it up in their hands to complete a closer inspection of the details. When the co-located learner needed to conduct a closer inspection of the gauge we needed to provide an option that provided a similar sense perception to picking up the manifold. The option we chose was to write a zoom camera ray cast script which was triggered by the dis-located user's mouse curser each time he/she clicked on the face of the mechanical gauge manifold. This script was similar to the camera switching script, which sets a camera right in front of the activated gauge (Figure 5.22). As previously stated, providing tag names for each of the learning object meant we could duplicate the command scripts to complete similar functions for other objects tagged as valve ratchet, electronic leak detector, weighing scales, recovery unit operation, expansion valve inspection and temperature compactor chart (Figure 5.23). Once we were satisfied that each training laboratory instruction, action and interaction could be mimicked in our VR environment we could then begin to develop the next phase of our design.

Phase 3 is provides the possibility for socialisation of the dis-located learners. This involved developing network connectivity and conference call communication features. Game files built in Unity can be built to the standard specification for a number of operating systems for distribution purposes ('compile make an .APK file or make an .EXE file'). Once the file is compiled the simplest method of distribution is to email it to the intended learners for downloading to their hardware device. Other slightly more sophisticated distribution options included the use of an installer to download the game file and put into a directory on the hardware device. A final method of distribution is to offer it through google play online store or Apple iTunes online store as a free application download. Using any of these forms of distribution enables learners to access and interact with the game on their local server but does not provide for social networking connectivity.

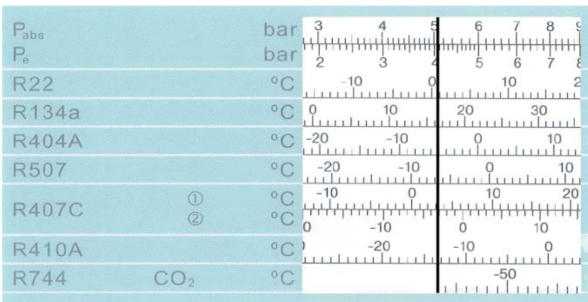


Figure 5.23: VR models of pressure temperature comparator scale/chart

Part of our requirements was to model real time social learning and therefore we needed a

Table 5.1: List of learning instructions and corresponding learning objects, learning activities and their cognitive contributions

Training laboratory instruction	**Learning objects**	**Learning activity**	**Contribution of learning object**
Conduct a visual survey to determine system operating conditions	A functioning refrigeration system and an operational thermometer (Figure 5.15)	Explain the theory of the operating principles of a vapour compression system and demonstrate your understanding of how this applies to a normal functioning refrigeration system	Object with ray cast script to trigger the thermometer animation script and provide expected temperature feedback to learner user.
Identify the refrigerant gas classification in the refrigeration system	A functioning refrigeration system, thermometer (Figure 5.15) and a pressure temperature comparator scale/chart (Figure 5.21)	Explain the theory of Gay-Lussac's law (one part of the ideal gas law) and demonstrate how this is applied to identify refrigerant gas classification	Object ray cast script to trigger the thermometer temperature animation script and provide expected temperature feedback to learner user. Comparator scale/chart with animation script to convert temperature reading to the corresponding expected pressure
Connect and disconnect mechanical pressure gauge set	A functioning refrigeration system and a mechanical pressure gauge set and a mechanical ratchet	Apply the purge sequence to demonstrate cognitive knowledge about the effects of air ingress and F-Gas regulations	Animation command script to assist the learner to complete purge and pump down sequence of steps
Identify the pressure and corresponding latent or sensible heat temperature of the refrigerant gas at each of the main refrigeration components	A functioning refrigeration system, thermometer (Figure 5.15) and a mechanical pressure gauge set	Explain the theory of a non-ideal vapour compression cycle and demonstrate how refrigeration system operating parameters are set to ensure non-ideal vapour compression is achieved and maintained.	Object with ray cast script to trigger the thermometer animation script and provide expected temperature feedback to learner user. A gauge with animation script to provide feedback on operation pressures
Identify mechanical fault characteristics	A functioning refrigeration system, thermometer (Figure 5.15) and a mechanical pressure gauge set	Demonstrate level of ability towards critical thinking and fault finding analysis	Animation and ray cast scripts for each learning objects must be re-written to give false readings corresponding to the expected temperature/pressures for specific malfunctioning operating values.

networked multiplayer connection for real time communication, multiple screen control and conference call communication. UnityPhotonTM provided real time networking software that included a network room. Essentially when the learners were connected through Photon, it acted as the network manager showing who is available to meet online (in the network chatroom). We had to purchase this software from the Unity asset store and upload it to our game file so as to have access to the networking API scripts. Having uploaded this software we could then write into any unity script the word ‘photon’ this is the tag command to connect the game file to the networking room. For example, line 2320 ‘PhotonNetwork.offlinemode.(…)’ and line 2325 ‘PhotonView.RPC.(….)’ in Figure 5.18.

In the real world training laboratory verbal discussions (peer to peer and learner to educator) take place about the learning instructions. To facilitate dis-located learners to communicate in a similar way while connected online we choose to purchase additional plugin software uSpeak™ to enable voice communication across the networked environment. Again this was available to purchase from the unity asset store. U-speak recorded audible noise picked up by the microphones belonging to the hardware devices and created files which it sent through the photon network manager software.

In the real world environment co-located students gathered in a specific place (the training classroom) to complete the learning instructions. In an attempt to provide dis-located learners with the sensation of meeting in a specific VR space (extend the sense of socialization) and in an effort to provide us with the ability to track learner user progress and level of activity, we embedded our Unity game file into a URL website. Web-based functionality required us to include script in our Unity game file that commands the user’s log on sequence to the shared network. The website module was setup to be responsible for resource information storage and distribution and to provide the interface-component for the network and voice communication software. The components of the website are information pages and materials that include typical features expected from web-based networked host providers [18][3]. Figure 5.24 presents the functional specification and decomposition of the working prototype website. Outlined are the functions of the prototype website and how the prototype (i) supplies, (ii)

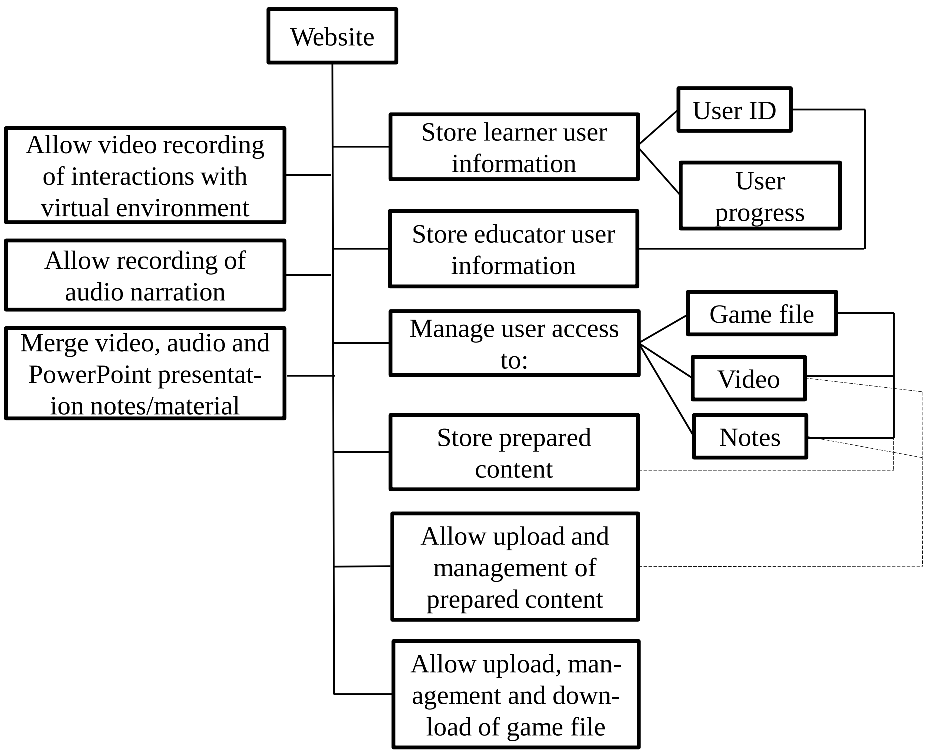


Figure 5.24: Functional specification and decomposition of the website

stores, and (iii) manages the relevant files over the network to ensure the user commands are reflected accurately. The website provides for social networking and plays an instrumental role for the network management of the system.

5.4 Piloting, testing and enhancement

5.4.1 Piloting and testing with expert group

An expert focus group based at the Dublin Institute of Technology was given access to a first version working prototype WBS-LS in advance of a scheduled meeting. Their objective was to engage with the system and evaluate its design as a learning tool that provides higher level problem solving knowledge aggregation. While interacting with the system the group was asked to consider if there were issues with (i) accessibility/usability and (ii) the problem solving learning scenarios. In other words rather than inspecting individual elements, the expert group was asked to approach the system as learner users and confirm if the learning scenarios could invoke self-learning. When the expert group attended the focus group session they worked together to discuss their experience of interacting with the system. At the end of the meeting they were invited to complete a short online survey questionnaire individually and privately, so as not to influence each other's ratings.

The survey consisted of a number of statements relating to the elements of the prototype. The participants were asked to tick one of the numbers on the Likert scale to indicate their response. A five indicates that they strongly agree and a 1 indicates that they strongly disagree. Figure 5.25 shows a summary of how the individuals responded, interpreted as follows: 36.4% of the participants who responded strongly agreed with the statement that 'the 3D models are a good representation of the real world components'. 45% agreed with this statement and the remaining 18.2% of respondents neither agree nor disagree with this statement leaving 0% who disagree or strongly disagree.

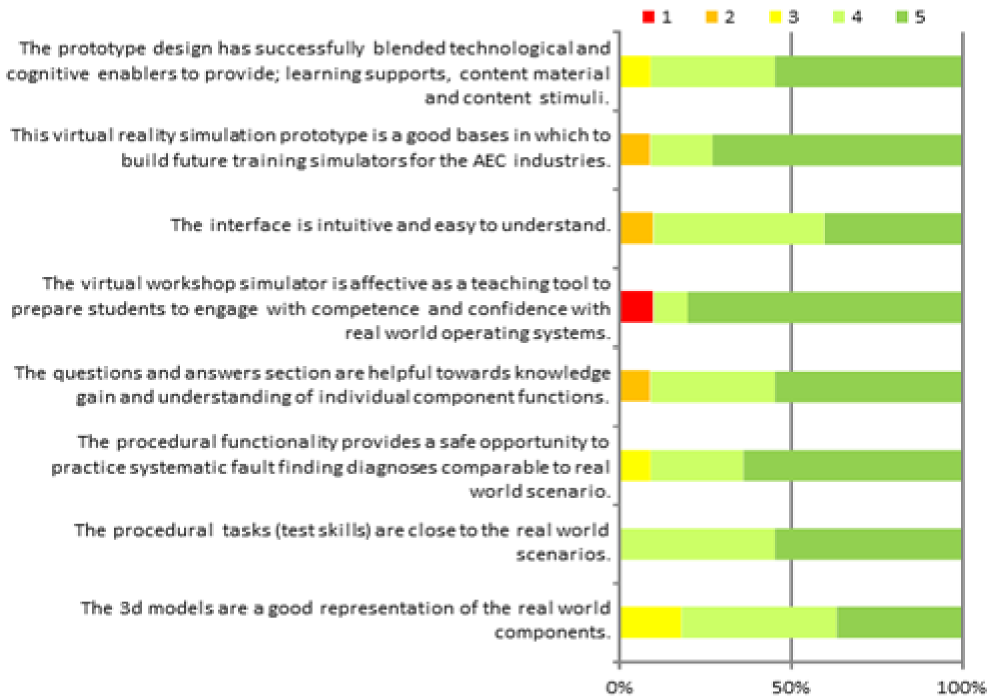
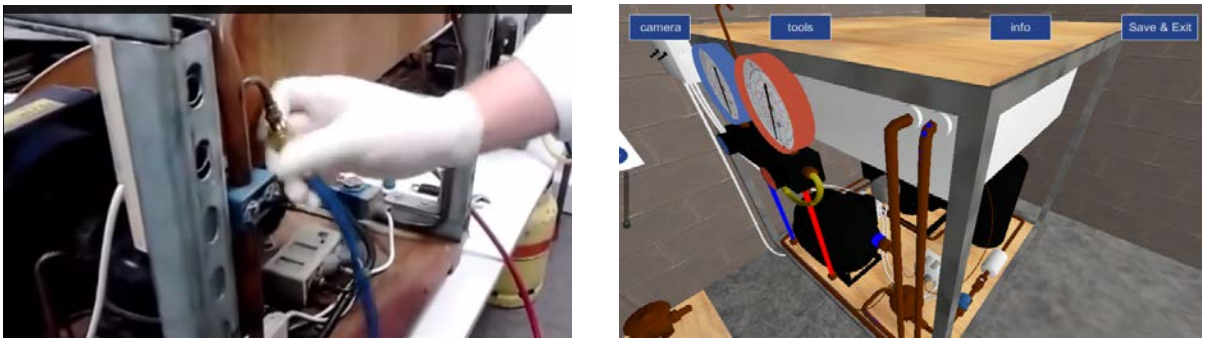


Figure 5.25: Summaries the individual responses of the focus group members

When comparing the online procedural tasks with the real world training classroom equivalents, 54.5% of the focus group respondents strongly agreed with the statement; ‘the procedural tasks (test skills) are close to the real world scenarios. The remaining 45.5% agreed with this statement and 0% responses for neither agree or disagree, disagree and strongly disagree. When it was stated that ‘the procedural functionality provides a safe opportunity to practice systematic fault finding diagnoses comparable to real world scenario’, the responses were: 63.3% strongly agree, 27.3% agree, 9.1% neither agree nor disagree, and 0% for disagree and strongly disagree. The use of multiple choice questions in the ‘question and answer section’ resulted in a 54.5% strongly agree reaction concerning being ‘helpful towards knowledge gain and understanding of individual component functions’. Some 36.4% of the interrogated learners agreed with this statement, while 0% neither agreed nor disagreed with it, 9.1% disagreed, and 0% strongly disagreed.

The next statement was: ‘The virtual workshop simulator is affective as a teaching tool to prepare students to engage with competence and confidence with real world operating systems’. The response results for this statement were as follows: 80% of the interrogated learners strongly agreed, 10% agreed, 0% neither agreed nor disagreed, 0% disagreed, and 10% strongly disagreed. In relation to the human computer interface (HCI) we stated that ‘the interface is intuitive and easy to understand’. The responses were: 40% strongly agreed, 50% agreed, 0% neither agreed nor disagreed, 10% disagreed and 0% strongly disagreed. The statement concerning the potential of the presented system to evolve as a base platform which can be used to build procedural skills training for other construction engineering discipline was accepted by 72.7% of participants, who strongly agreed with this statement. A further 18.2% of the interrogated learners agreed, 0% neither agreed nor disagreed, 9.1% disagreed, and 0% strongly disagreed. The last statement was related to the success of our blending of the enablers sufficiently enough ‘to provide learning supports, content material, and content stimuli’. Some 54.5% of the interrogated learners strongly agreed, 36.4% for agreed, 9.1% neither agreed nor disagreed, 0% disagreed, and 0% strongly disagreed.

The conduct of the focus group meeting consisted of a short presentation followed by a group discussion on each of the key elements of the presentation and on each member’s individual experience with the system. The presentation consisted of extracts of the digital video recordings, and focused on examples of procedural tasks which took place in the real world training classroom. For each of these extracts a corresponding digital footage was provided to demonstrate how the VR training classroom replicated the real world procedural tasks (Figure



a b

Figure 5.26: Comparison of the real world object with the VR generated object: (a) extract of a real world video, (b) extract of a VR world video

5.26a and 5.26 b).

5.4.2 The introduced enhancements

The focus group conducted a critical evaluation of the theoretical dimensions identified for the working prototype to validate them as true theoretical underpinnings. Building the prototype provided a means to demonstrate how to blend technology enablers with social and cognitive enablers. From the outset the VR environment and its learning functions were based on (i) cognitive enabler's theory; (ii) technological enabler's theory and (iii) social enabler's theory. The group confirmed the theoretical blending of the enablers could only be validated during the utility testing of the system. They identified that what was missing for their interaction with the system was a set of clear learning instructions. Instructional process helps to bring about over several successive stages the transformation of information into the learner's long term memory. The purpose of instruction is to arrange external events that will support internal learning. Instructional design must also consider the principles associated with learning in a social-cultural environment and there effect on the selection of educational outcomes. At the beginning of the program, CEE provides learners with a set of practical steps incorporating the principles of instructional design. Wagner developed the technique of instructional curriculum mapping to integrate intellectual skills with supporting objectives from different domains while Briggs expanded on prescriptions for media based instructional functions [4].

The learning approach of CEE tends to place an emphasis on the behaviourism and constructionism learning paradigms. The expert focus group concluded that a set of learning instructions needed to be applied to the WBS-LS and had to be equal to the instructions provided to the co-located learners. Therefore it was suggested that a common learning module be delivered to both types of learners leaving only the mode of delivery to differ. This meant identifying a suitable learning module for which the learning instructions could be utilised to enable both types of learners meet the prescribed learning outcomes. The 'principles of refrigeration' module is already applied to give learning instruction to the co-located learners in the real world classroom and therefore was deemed suitable to apply it to the VR learning environment.

During the discussions, the process of "*scenario learning*" was suggested in order to identify the principal psychological and perceptive immersive components which could improve the dis-located learner's experience. The process is about the construction of learning scenarios that enable the dis-located learners to demonstrate their understanding of the learning instructions provided. A scenario learning approach is an additional aspect to conventional software scenario testing. Conventional software scenario testing methods are defined through tasks described by fictional stories, identifying what the users require. Then once identified, these requirements are used for testing. It was the opinion of the expert group that scenario learning introduces discussion and dialogue creating continual input into the design between the learner users and the educator user. The scenario learning approach accordingly will introduce opportunities to change mental models of the educator user's; understanding, predictability and uncertainty [5]. Scenario learning is intended to allow those involved to engage with each other and freely exchange ideas, perception, concerns and discoveries to inspire decision making, generating further reflection, review and revision of system design [6].

The expert group suggested that the WBS-LS could be enhanced if the learning material presented was divided up into three sections (i) video, (ii) image and text, and (iii) interactive. In addition, the learning instructions should be clearly defined and from this, each learner should be able to gain a strong sense of what they need to do. The real world classroom instructions were delivered by the tutor via a live demonstration to highlight what was expected. The expert group advised us to produce a number of short demonstration video tutorials to assist the dis-located learners with both the digital interface and to identify the learning expectations. When we began to produce these short demonstration videos we realised that we had not included instruction on other real world classroom activities such as how to (i) braze, (ii) flare, and (iii) swage interconnecting copper tubing. These were extra learning materials that we needed to include prior to the experimental field testing (implementation testing).

5.5 Discussion and conclusions

5.5.1 Limitations of the working prototype

As previously stated, during the period prior to the focus group meeting, our experts engaged with the WBS-LS working prototype. Poor internet was flagged as an obstacle which caused internet connectivity problems for some of the group. Upon further investigation we discovered Internet reliability and stability was more important than bandwidth speed. In fact we were able to determine that networked connection through UnityPhoton required a reliable and stable internet as appose to a fast upload and download bandwidth. The main reason for this, as explained in Sub-section 5.3.2, is because messages relating to function and action scripts (information packages) are transmitted across the UnityPhoton network management application software. When these information packages became greater than the amount of data any one of the connected individuals internet connection was capable of handling, then these information packages became lost data for that individual. For example an excessive build-up of sound (voice) communication information packages occurred each time a new user came online and joined the networked group. This was mainly because our focus group users had their microphones permanently on (as appose to activate when they had something to say and de-activate when they were listening or observing).

The group members also used open speakers instead of private earphones. The result of relying on open speaker systems while leaving the microphone permanently ‘on’, meant that ambient noises around each of the users work space (door opening, outside traffic, radio on in the background) created an ever increasing number of information packages. Adding to the excessive build-up of sound information packages was the additional noise coming through each open speaker set (user 1 background noise was broadcast by user 2’s speaker set and therefore became additional background noise for user 2). The absence of a device such as earphones proved to be the very disruptive for users when their internet stability was unreliable for networked connectivity.

The computer programming to resolving the excessive build-up of voice communication information packages requires a sophisticated software. There were software solutions available at the time. They had the algorithms that could identify real communication and filter the necessary information packages accordingly. The digital literacy knowledge required to incorporate such software is way in excess of our current level. Skype is a good example of a videoconferencing communication software that has algorithms that can identify and purge the excess unwanted noise data thereby eliminating the build-up of information packages that lead to loss of important data. With this in mind we set about looking at how we could include Skype software or similar to our game file.

Directly relating to the usability evaluation and human-computer interface, the expert group discussed if the prototype as presented could be less cluttered and more intuitive. As highlighted in chapter 2, how humans view and evaluate a simulated interface is based on that individual's level of knowledge domain and experience in the real world. These differences have a high influence on the success of simulated environments as educational tools [7]. The provision of a GUI that convinces the user of their presence when navigating through the 3D space, invokes actions and reactions equal to real time experience. In other words the sense of presence experienced invokes cognitive responses equal to real world experiential actions and reactions [8]. As a result of the discussion around the interface design we were required to take a second look at the menu system before we could proceed to the implementation phase of our research.

5.5.2 Reflections concerning the technology

When we began this research in 2013, there were six emerging technologies that were predicated as up and coming teaching, learning and creative inquiry technological enablers. These were (i) massively open online courses (MOOC), (ii) increased use of tablet devices, (iii) games, (iv) gamification, (v) wearable technology and (vi) 3D printing [9].In the 'New Media Horizon report of 2017 they look back over the last 15 years and observe that technological trends tend to evolve rapidly year on year with a fresh perspective and new developments [10]. For example the research to date indicates that MOOC's (first initiated by higher education institutes in 2008) have been most successful in the cooperate sector as an integral tool for establishing and maintaining company recruitment, culture and training structure[11]. Other examples include the addition of mobile phone virtual reality, web-based chatbots and wearable immersive applications all adding more functionality to enhance further learning [7]. Having reviewed the technological trends of the past number of years, the 2017 NMH report predicts that the next six emerging technological enablers are (i) adaptive learning technologies, (ii) mobile learning, (iii) the internet of things, (iv) next generation learning management systems (LMS), (v) artificial intelligence (AI) and (vi) natural user interface. This report also identifies the key inconsistencies in quality of internet connectivity and the level of digital literacy between learners [10].

Creative problem solving using technological enablers requires a high level of digital literacy. According to Ventimglia and Pullman digital literacy is more than being able to use the must up to date technologies. It is as much about the development of digital context skills and the ability to critically evaluate digital content[17]. This means there is a need for higher education institutes to provide continued professional development support to improve the levels of digital literacy for teaching staff[18]. On the other hand organisation such as Jisc recommend learner educator partnerships are more effective towards the design, development and improvement of digital rich learning environments[19]. The future development/improvement of

[17] http://er.educause.edu/articles/2016/3/from-written-to-digitalthe-new-literacy [accessed June 2017]
[18] https://ec.europa.eu/jrc/en/digcomporg/framework [accessed June 2017]
[19] https://www.jisc.ac.uk/guides/developing-successful-studentstaff-partnership [accessed June 2017]

the prototype developed during the promotion research project should involve input from learners, who have a direct need to use the system. This will require further professional development of the levels of digital literacy for both educator and learner. It might even involve re-designing the WBS-LS VR environment using the principles of 'open world game design'. This involves the addition of tools that will enable the learners to expand the learning content and then share it with other users [12].

5.5.3 Conclusions

In research cycle 4 the focus was on using the conceptual design framework presented in chapter four (RC3) to build a prototype pilot and establish proof of concept. In order to test the effectiveness of our conceptual design we built a working prototype to virtually replicate the content and process of learning real world refrigeration maintenance and problem solving skills. At the heart of this enabler design framework is a complex educational tool which will need to be put through a situated field experiment in RC5. As part of this research promotion the prototype WBS-LS was distributed among expert teaching practitioners and professional practitioners with computer science knowledge. This piloting confirmed the conceptual design framework when applied to the development of web-based stimulated learning tool was effective in providing context rich teaching and learning web-based learning material for dis-located CE learners.

In line with what the literature proposes nowadays, the essentials were identified as; (i) cyber components for learners to interact with, (ii) interface components, which enable cyber components to interact with the equivalent physical components, (iii) physical components to support the completion of learning activities, (iv) feedback and/or monitoring components, and (v) networking capabilities [13] were included in the presented prototype and in some cases further enhancements were suggested to bridge identified shortfalls. Overall the prototype design was sensitive to two types of intended user's and offered a common interface for both educator and learner users. It was highlighted that digital learners develop personal websites commonly known as 'Blogs' to manage their information requirements and content development and that the URL webpages utilised in our WBS-LS (wordPress) are content that is all too familiar to these type of learner users.

As part of the overall focus group discussion, the group gave careful consideration to whether or not the prototype had managed to potentially meet the challenges (as identified in the literature) associated with introducing technology into learning and teaching. Specifically they considered the five main challenges of (i) organising collaborative learning among learners, (ii) communicating the structure of the learning system to the student so they understand how the technology is applied, (iii) provision of cognitive learning content to ensure the students gain knowledge through collaborative learning projects, (iv) ensuring students receive timely feedback and are facilitated in the sharing of content such as cognitive learning material, and (v) how to pitch the learning content at the individual students level of ability while at the same time keeping pace with group learning needs [14].

Developing a working prototype proved to be an integral part of an iterative user-centred design [15]. Presenting it to a focus group of experts was an efficient and effective way to refine and improve on our design as it fostered discussion, exploration, testing and iterative revision [16]. The prototype presented to the expert focus group provided a primary solution to the application of our conceptual design towards building a WBS-LS fit for situated field testing.

Prototyping WBS-LS as a testable implementation provided an effective communication tool for the focus group experts and turned out to be far more powerful than either narrative proses or static visual models, which could have been used as tools to portray the intended functionality of the prototype [17].

5.6 References

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Chapter 6

Research cycle 5
Utility testing of the prototype system

6.1. Introduction

6.1.1. Objectives and arrangement

The main objective of this research cycle was to validate if the pilot implementation (prototype) of the WBS-LS can meet with *real life requirements and contexts*, and to express the utility of the virtual reality (VR) system in terms of indicators and tangible measures. The concrete objectives of validation were:

- To teach groups of students enrolled on the educational module called ‘Principles of Refrigeration’, as dislocated learners using the prototype system as the learning and teaching environment.
- To teach groups of learners enrolled on ‘Principles of Refrigeration’ module as co-located learners using the traditional classroom and workshop laboratory as the learning and teaching environment.
- To set a common procedural skills test for both types of learners and to assess their individual performance
- To set a common theory test for both types of learners and to assess their individual performance.
- To conduct a statistical comparative analysis of individual results for both theory and skills performance.
- To determine if learner performance of the prototype users is equal to or better than the learner performance of the classroom and workshop laboratory users.
- To conduct a user satisfaction survey among learners who took part in remotely attended course.

Towards this end experiments were designed and conducted. Figure 6.1 shows the research model that was used to organize the activities towards achieving the above objectives of validation and to set up the necessary experiments.

The preparation for the experiments involved a purposive sampling of learners who enrolled for the learning module called ‘Principles of Refrigeration’. Altogether (a population of) 38 learners enrolled. Half of them (that is 19) participated as dislocated learners and were taught through using the web-based environment. They were involved in *remote learning*. The remaining 50% (another 19) participated as co-located learners and were taught in the purpose-designed classroom (actually a laboratory environment) by using traditional teaching means.

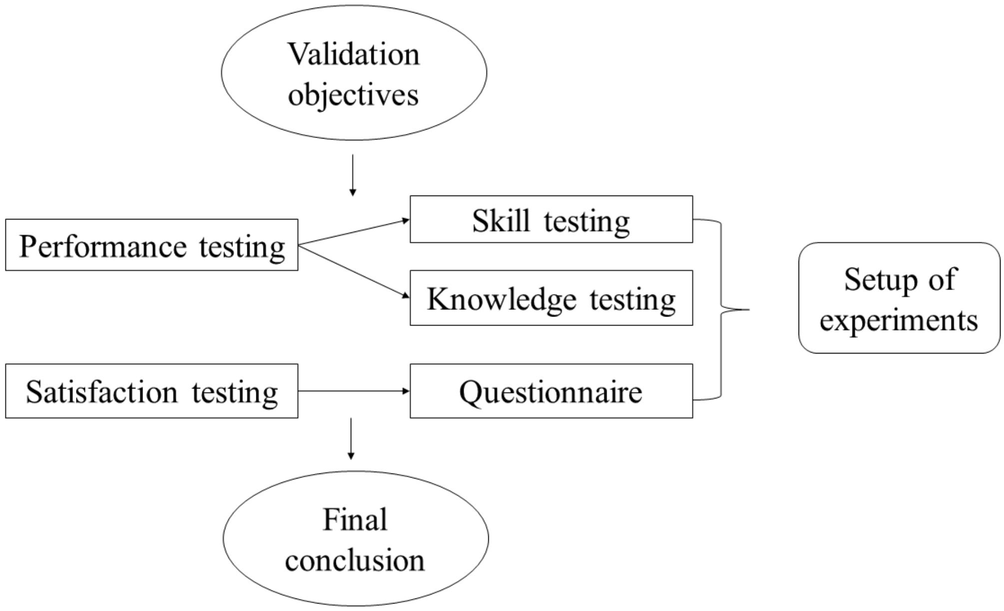


Figure 6.1: Research model

They were involved in *on-site learning*. Upon completion of the study in the module, both types of learners were assessed in terms of their performance. The performance assessment included tests concerning the obtained common procedural skills and the extension of the *theoretical knowledge* of the learners. The performance results of the two types of learners were statistically processed and evaluated. The findings in the two tests were subjected to a comparative analysis in order to determine the effectiveness of the WBS-LS prototype as a novel learning and teaching environment. A separate *learner satisfaction* survey was also completed with the involvement of the remote learners.

6.1.2. Performance and satisfaction as dual objectives of the study

The prototype WBS-LS was supposed to guarantee the same level of competences of the remote learners as that could be achieved with on-site learners. From the five aspects of competences discussed in [1] we considered the skill and knowledge aspects. Performance with regards to the obtained skills and knowledge was tested as a quantitative measure of study achievement for both co-located and dislocated learners. This was extended with evaluating the satisfaction of the learners with regards to using the prototype WBS-LS in comparison with the classroom-based conventional means of knowledge delivery and skills development. The main goal of these experiments was to see if the technological, cognitive and social enablers blended in the prototype WBS-LS could motivate dislocated learners to achieve learning results equal to or better than that of their co-located counterparts. A secondary goal was to discover if the overall user interface design of the prototype WBS-LS needed amends, changes, or improvement in order to achieve the best possible overall learner experience. In this validation the system and content developer users of the prototype WBS-LS have not been involved. This is left for further research.

The utility testing was based on the learning scenarios, which were outlined in Chapter 5. These scenarios were also useful for identifying (i) problems with the prototype, (ii) the potential to make improvements to the prototype, and (iii) validate the prototype during implementation testing [2][3]. The learning scenarios were orientated towards craft-based technicians, who had no formal knowledge but intended to learn the fundamental principles of refrigeration engineering. The design of the WBS-LS learner satisfaction survey was based on functionality and usability validation. An additional outcome from this survey was to determine how effective the prototype WBS-LS was as an extendable virtual learning and teaching tool [4][5][6].

The first experiment was designed to measure the level of procedural skills obtained by the dislocated learners against the level of procedural skills obtained by the co-located learner's counterparts. The second experiment was designed to measure the knowledge gain through a summative common theory examination and compare the level of performance outcomes between each learner type. The overall usability of the prototype VR environment was measured separately by using a learner satisfaction questionnaire, which interrogated about the ease of use of the VR environment. In the end we wanted to get a critical view on the practical utility of the proposed learning system and approach.

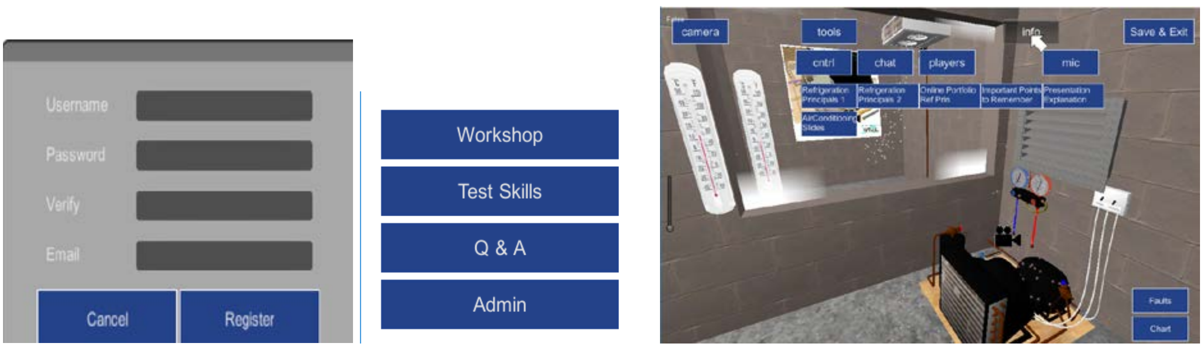
6.1.3. Environment for the test experiments

Concerning the practical execution of the performance experiments, we had to consider a number of issues:

- Hardware/software compatibility.
- Bandwidth connectivity requirements.
- Learning scenario design to disseminate knowledge so that both learner types could complete the procedural skills and theory tests

The WBS-LS prototype provided learners with a simple website (Figure; 6.2) which hosted the (i) VR environment Unity file, (ii) tutorial U-tube videos, which could be streamed or downloaded and (iii) study reference notes/materials. The learners accessed the website remotely to complete pervasive learning or to communicate peer to peer and/or learner to tutor as appropriate. The learning scenarios for the common skills procedural and the theory test were designed in accordance with the learning outcomes described in the module 'Refrigeration Principles'. To demonstrate an understanding of

- refrigeration principles,
- system components,
- refrigeration system types,



a b c

Figure 6.2: Screen save of the WBS-LS prototype interface: (a) New learner registration, (b) Menu options, (c) Learner interface with drop down menu

- refrigerant gas properties,
- mechanical controls, and
- health and safety.

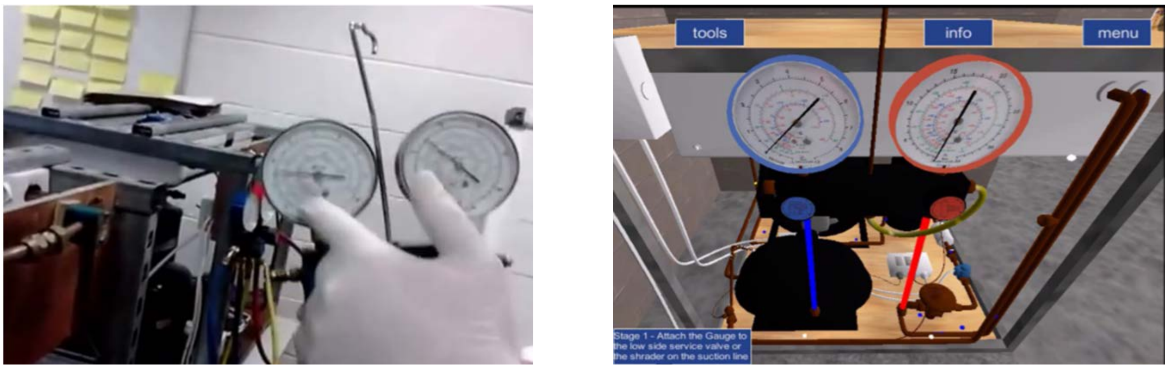
Those classified as co-located control groups had no access to the WBS-LS but were exposed to the learning scenarios through the use of class room based; lecturers, skills practice and face to face (F2F) knowledge sharing. Each dislocated control group was given access to the WBS-LS for online lecturers, skills demonstration practice and general knowledge gain. Figure 6.3a shows a photo image of the real world classroom equipment used by the co-located learners. Figure 6.3b shows a digital image of the equipment realized in the VR environment for use by dislocated learners.

Some pilot tests were made in the process of setting up the experimental environment with the purpose all eliminating all bottleneck and providing optimal conditions for the tests. The most important observations were as follows: The WBS-LS prototype was limited by the number of functionality and usability software scripts we were capable of writing. The more functionality scripts introduced, the more increased is the need to develop more programmer expertise. The larger the number of learners online at the same time led to a larger amount of unnecessary data exchange in the form of background real world environmental noise. This used up internet bandwidth, produced disruptive sounds and in times of poor internet connection the prototype was unable to purge the built up backlog of data being stored locally and thus resulted in information lag, loss and learners becoming frustrated and de-motivated.

These observations were considered and preventive measures were taken to avoid the appearance of these mishaps. Sound recorded data for both upload and download was the biggest cause of disruptive data creating bottlenecks. We removed the voice chat unity photon plug in feature from our Unity file and substituted voice communication by setting up a skype group call for learners to dial into and run in the background when interacting the WBS-LS prototype VR environment.

6.1.4. Sampling subjects for the experiments

The module ‘Refrigeration Principles’ was advertised to suitable participants employed by mechanical, electrical and facilities maintenance companies. Those who were suitably qualified were enrolled and classified as either co or dislocated learners using purposive sample criterion [7]. The purposive sampling criterion was based on aspects such as;



a b

Figure 6.3: Physical and digital images of the educational equipment: (a) image of the classroom-based equipment, and (b) image of the WBS-LS equipment

- Expertise and experience of the subjects were non refrigeration based, and therefore needed training in the specialised area of refrigeration engineering.
- The subject was employed in a role with responsibilities towards maintenance and service of refrigeration equipment.
- The subject's knowledge of refrigeration principles was limited.

The sample population eligible to take the module is small because of the specialist nature of refrigeration engineering. Convenience sampling was applied to the sample numbers used, 38 eligible learners participated. 50% (19 numerically) were randomly selected to participate as part-time dislocated learners while the other 50% (19 numerically) were selected as co-located part- time-learners. There was only one female who applied to complete the module and was randomly selected as a dislocated learner. One participant who experienced poor internet infrastructure and used a non-compatible hardware device, was excluded from the dislocated learner performance data. Before the experiments commenced, participants gave consent to written assurances that all data would be handled and stored in accordance with Irish data protection law.

6.2. Theory testing and skill-testing experiments

6.2.1. Preparing the learners for skill-test and theory test experiments

Both learner types were subjected to six weeks of preparation before they could participate in the skills test and theory test experiments. In the case of the dislocated groups, each learner registered on the website self-choosing a user name and password as their unique identifier. This feature insures all data captured and stored related to an individual remained with the specific user registration details. All variables for progress is stored on line on the web server and temporally copied (an instance is made) to the learner device each time the learner logs on to the website. All changes/progress made by the learner while logged on, is saved and uploaded to the web server during the save and exit logging out sequence. It is this save and exit feature that over writes historically data stored relating to the unique user name.

For the dislocated learners the six week preparation time was broken up into the following segments:

Week 1: The dislocated learners were initially invited to meet with each other and the educator tutor (main author) in a real world classroom. The objectives of this 1 day face to face (F2F) meeting were as follows;

- To give a demonstration of how to navigate and operate the VR environment (Figure 6.4).
- To give assistance with uploading the WBS-LS file to a compatible hardware device.
- To give an introductory lecture inclusive of an introduction to the module aim and learning outcomes.

Weeks 2 to 5: The dislocated learners logged onto the WBS-LS to meet the following objectives:

- To log on to the WBS-LS and interact with the virtual laboratory equipment and each other at a time and place of their individual or collective choosing.

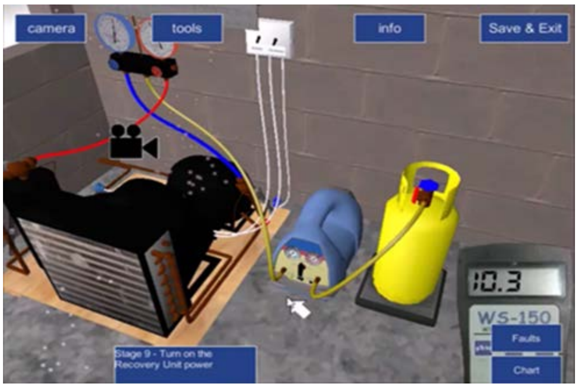


Figure 6.4: Demonstration on how to navigate and operate the VR environment

- To log onto the WBS-LS anytime anywhere to practice the procedural tasks listed in Table 6.1.
- To log on to the WBS-LS at a specific time one evening per week for an intensive 2 hour live lecture which was recorded and edited for distribution after.

Week 6: The dislocated learners were brought back to the real world classroom/laboratory to complete the skills test and theory test experiments.

In the case of the co-located learning groups the six week preparation time was broken up into the following segments;

Week 1: The co-located learners were invited to meet with each other and the educator tutor (main author) in a real world classroom. The objectives of this one day face to face (F2F) meeting were as follows;

- To provide a demonstration of how to operate the real world classroom/laboratory equipment (Figure 6.5).
- To give an introductory lecture inclusive of an introduction to the module aim and learning outcomes.

Weeks 2 to 5: The co-located learners are expected to continue with independent learning until they meet again with the tutor and each other on day 2 and for each of the subsequent weeks (days 3, 4 and 5). For the co-located learner it must be noted that;

- There is no formal mechanism for co-located learners to meet or interact with the classroom

Table 6.1: List of practical procedural skills

Task	Procedural Learning Scenario
1	Conduct visual survey
2	Identify type of refrigerant gas in system
3	Identify the physical state of the refrigerant gas as it circulates around the mechanical components
4	Complete a system leak test
5	Use correct tools to confirm correct refrigerant charge
6	Connect and dis-connect gauge manifold, minimise refrigerant purge
7	Identify symptoms of following fault scenarios; • Lack of condenser capacity • Lack of evaporator capacity • Lack of compressor capacity • Lack of expansion valve capacity

Figure 6.5: Demonstration on how to navigate and operate the classroom/laboratory equipment

laboratory equipment between lecture days.

- The co-located learners are allocated time on each meeting day to practice the procedural tasks listed on Table 6.1.

Week six: The co-located learners were brought back to the real world classroom/laboratory to complete the skills test and theory test experiments.

6.2.2. Setting up the knowledge-testing experiments

For the purpose of these experiments all reasonable steps were taken to ensure no interaction could take place between a co-located group and a dislocated group. Both types of learners were brought into a classroom and provided with a theory based exam paper to complete under a two hour closed book examination conditions. The marking criteria associated with the theory assessment for this module is provided in Table 6.2. Upon completion of the exam, participants handed up their exam scripts for marking and proceeded to the classroom laboratory for completion of the procedural skills test.

6.2.3 Setting up the skills-testing experiments

Both types of learners were brought into the classroom/laboratory and were observed by the examiner as they completed the procedural tasks outlined in Table 6.1. The marking criteria associated with the skills assessment for this module is provided in Table 6.3. Upon completion of the skills test the participants handed up a commissioning sheet which contains the participant's calculation methods to identify operating parameter settings.

Table 6.2: Theory test marking criteria

Theory Test Marking Criteria 30% Duration 2 hours	Available Marks	Candidate Mark
Section A: Short Answer Questions: answer any 5 out of the 6 questions available. Examiner to indicate the questions number answered:	Q__ 0-4 Q__ 0-4 Q__ 0-4 Q__ 0-4 Q__ 0-4	
Subtotal	20	
Section B: Structured Questions: Answer any 1 out of the 2 questions available. Examiner to indicate the question number answered.	Q__ 0-10	
Subtotal	10	
Total Mark	30	

6.2.4. Results of the theory and skills testing experiments

In order to prepare the data for comparative statistical analysis Tables 6.4 and 6.5 were populated with the performance results for each learner type. The results are divided up into the requisite control group category. Control groups A, C and E were co-located, while control groups B, D and F were dislocated. Each control group has a small number of learners (between 6 and 7) per group. Each learner's anonymity is protected by replacing their names with a student number. For example CGA1Co represents control group B, student number 1, co-located. CGB1Dis represents control group B, student number 1, dis-located. Beside each participant code is a mark. This mark relates to how the participant performed in the assessment. For the theory test the maximum number of marks is 30. CGA1Co has a performance score of 18/30 for the theory test as indicated in Table 6.4. For the skills test the maximum number of marks is 70 and CGA1Co scored 57/70 as indicated in Table 6.5.

Table 6.3: Skills test marking criteria

Skills Assessment Criteria 70% Duration 4 hours	Mark Range	Candidate Mark
Thorough understanding of safety procedures	0-6	
Clear understanding of task on hand	0-7	
Correct connection of gauge set to system where appropriate	0-4	
Systematic fault-finding procedure	0-5	
Appropriate methodology used to complete task successfully	0-6	
Relevant information collected	0-5	
Accurate calculations used	0-5	
Critical evaluation of correct refrigerant charge	0-5	
Correct removal of gauge set from system where necessary	0-3	
Appropriate procedures followed for system leak test	0-5	
Safe use of all tools and equipment	0-7	
All procedures carried out in an environmentally friendly manner	0-5	
Appropriate procedures followed to ensure the equipment was put back in line with correct operating parameters	0-7	
Maximum Candidate Mark	70	

6.2.5. Statistical comparative analysis

To analyse the data we needed to conduct a conformity analyses T-test to consider if the mean of the two samples are or are not statistically similar. Before carrying out the T-test, we firstly conducted two F-tests to check if the variances of the two samples (co-located and dislocated learners) were equal for both the theory test and the skills test data. For this study, the F-test Excel function was used to test the following hypotheses with a 95% confidence level [8]:

- H_0 (null hypothesis): the variance of the first dataset (co-located student performance) is equal to the variance of the second dataset (dislocated student performance).
- H_A (alternative hypothesis): the variance of the first dataset (co-located student performance) differs from the variance of the second dataset (dislocated student performance).

Table 6.4: Performance results of each control group for theory test

	Co-Located		Dis-located
Student Group	Theory test	Student Group	Theory test
Control Group A	Total 30 Marks	Control Group B	Total 30 marks
Student CGA1Co	18	Student CGB1Dis	24
Student CGA2Co	30	Student CGB2Dis	21
Student CGA3Co	24	Student CGB3Dis	22
Student CGA4Co	15	Student CGB4Dis	27
Student CGA5Co	27	Student CGB5Dis	26
Student CGA6Co	18		

	Co-Located		Dis-located
Student Group	Theory test	Student Group	Theory test
Control Group C	Total 30 Marks	**Control Group D**	Total 30 Marks
Student CGC1Co	21	Student CGD1Dis	17
Student CGC2Co	23	Student CGD2Dis	23
Student CGC3Co	21	Student CGD3Dis	23
Student CGC4Co	22	Student CGD4Dis	26
Student CGC5Co	17	Student CGD5Dis	23
Student CGC6Co	15	Student CGD6Dis	16

	Co-Located		Dis-located
Student Group	Theory test	Student Group	Theory test
Control Group E	Total 30 Marks	**Control Group F**	Total 30 Marks
Student CGE1Co	21	Student CGF1Dis	23
Student CGE2Co	15	Student CGF2Dis	27
Student CGE3Co	19	Student CGF3Dis	27
Student CGE4Co	13	Student CGF4Dis	29
Student CGE5Co	21	Student CGF5Dis	22
Student CGE6Co	19	Student CGF6Dis	21
Student CGE7Co	23	Student CGF7Dis	21

Table 6.5: Performance results of each control group for skills text

	Co-Located		Dis-located
Student Group	Skill Test	Student Group	Skill test
Control Group A	Total 70 Marks	**Control Group B**	Total 70 marks
Student CGA1Co	57	Student CGB1Dis	59
Student CGA2Co	56	Student CGB2Dis	38
Student CGA3Co	62	Student CGB3Dis	55
Student CGA4Co	56	Student CGB4Dis	44
Student CGA5Co	64	Student CGB5Dis	60
Student CGA6Co	55		

	Co-Located		Dis-located
Student Group	Skill test	Student Group	Skill test
Control Group C	Total 70 Marks	**Control Group D**	Total 70 Marks
Student CGC1Co	54	Student CGD1Dis	58
Student CGC2Co	62	Student CGD2Dis	61
Student CGC3Co	60	Student CGD3Dis	53
Student CGC4Co	62	Student CGD4Dis	61
Student CGC5Co	56	Student CGD5Dis	63
Student CGC6Co	51	Student CGD6Dis	38

	Co-Located		Dis-located
Student Group	Skill test	Student Group	Skill test
Control Group E	Total 70 Marks	**Control Group F**	Total 70 Marks
Student CGE1Co	64	Student CGF1Dis	49
Student CGE2Co	49	Student CGF2Dis	67
Student CGE3Co	60	Student CGF3Dis	68
Student CGE4Co	40	Student CGF4Dis	66
Student CGE5Co	67	Student CGF5Dis	68
Student CGE6Co	64	Student CGF6Dis	58
Student CGE7Co	56	Student CGF7Dis	55

With regard to the first F-test conducted Table 6.6 summarises the results of the theory test performance when comparing co-located student performance (Variable 1) and dislocated student performance (Variable 2) for the theory performance results. The Null hypothesis H_0 is acceptable if F critical is higher than the calculated F; this is the case (2.256671 > 1.56752). Therefore the variances of both co-located and dislocated populations can be considered equal at a 95% certainty level. With regard to the second F-test conducted Table 6.7 summarises the performance results of the skills test when comparing co-located student performance (Variable 1) and dislocated student performance (Variable 2) for the skill performance results. F critical

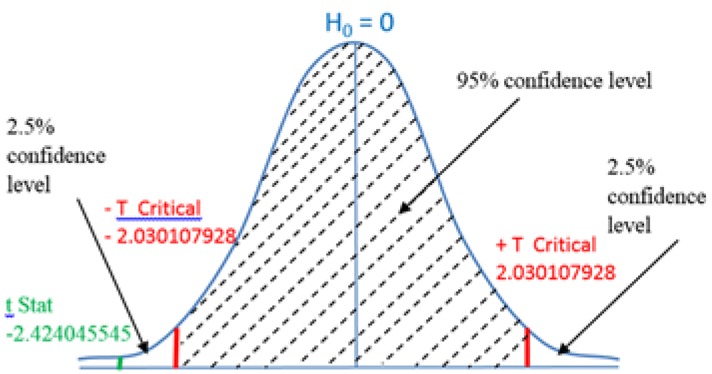


Figure 6.6: The t-test output graph for the theory test

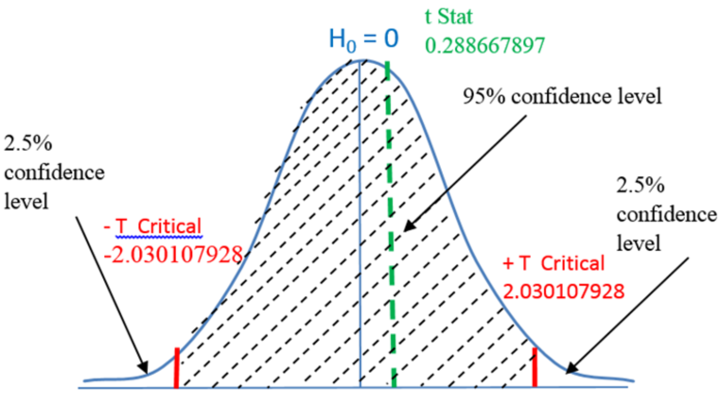


Figure 6.7: The t-test output graph for the skill test

(value of 2.232546) is higher than the calculated F (value of 2.216454); in this case, the Null hypothesis H_0 is accepted and the variances of the two populations can be considered equal.

Having completed the F-test for the theory and skills performance data and concluded that the variance of the first dataset is equal to the variance of the second dataset we went on to conduct a two-sample assuming equal variances t-test. As the sample size is statistically relatively small and the data has an approximately normal distribution, t-test is a suitable statistical method [9]. The purpose of our t-test is to test the null H_0 hypothesis; the means of the two datasets can be considered equal, at a 95% confidence level [10]. Table 6.8 shows the results for the t-test for the theory performance dataset. For the skills performance dataset, the same t-test (t-test: two-

Table 6.6: F-test result for theory performance

	Variable 1	*Variable 2*
Mean	20.10526	23.22222
Variance	18.54386	11.83007
Observations	19	18
df	18	17
F	1.56752	
P(F<=f) one-tail	0.179794	
F Critical one-tail	2.256671	

Table 6.7: F-test result for skills performance

	Variable 1	*Variable 2*
Mean	56.72222	57.47368
Variance	87.27124	39.37427
Observations	18	19
df	17	18
F	2.216454	
P(F<=f) one-tail	0.051509	
F Critical one-tail	2.232546	

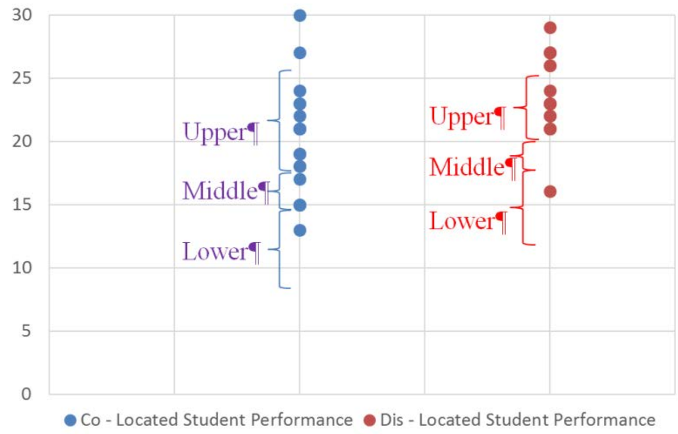


Figure 6.8: Performance of the students in the theory test

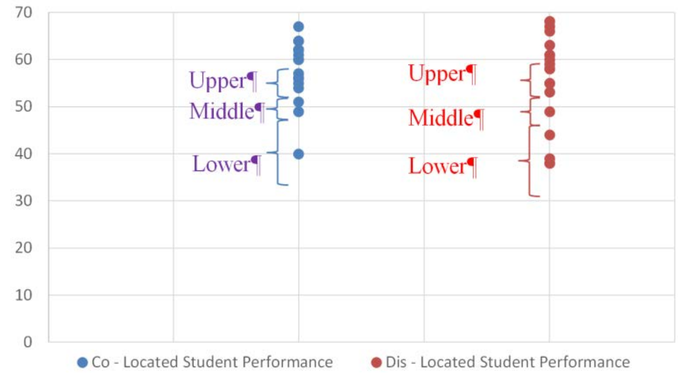


Figure 6.9: Performance of the students in the skill test

sample assuming equal variances) was conducted and the results are presented in Table 6.9.

6.2.6 Outcome of the statistical analysis

The 95% confidence is defined by any values between -t Critical two tail and +t Critical two tail; therefore, if t Stat falls outside this interval, the null hypothesis H_0 is rejected. As t Stat falls outside the +- t Critical interval (-2.424045545 < -2.030107928), H_0 cannot be accepted (Figure 6.6). As a result from this first t-test, the mean of theory test for dis-located learners is assumed to be statically different to the mean for co-located students therefore the alternative hypotheses H_A is accepted with a confidence level of 95%. For the skills performance test the t Stat falls clearly inside the +- Critical Interval (-2.030107928 < -0.288667897 < 2.030107928), therefor the null hypothesis H_0 is accepted (Figure 6.7). The mean for skills test between dislocated and co-located learner does not statistically differ. The t-test results suggest that the learners' performance for the theory exam differs between co-located and dislocated samples and for the skills performance exam the results between the dislocated and the co-located do not differ.

6.2.7. Comparison of the blended results

In the comparison of the distribution, the data included in Figure 6.8 and Figure 6.9 were used. The theory performance results were divided into three equal-interval categories, i.e. range of observed values categorised into equal sized bins [11]: (i) Lower: six lowest marks, (ii) Upper: six highest test marks and (iii) Middle: other marks in-between (six for co-located; seven for dislocated). The main findings are as follows:

Table 6.8: T-test result for theory performance

	Variable 1	*Variable 2*
Mean	20.10526316	23.22222222
Variance	18.54385965	11.83006536
Observations	19	18
Pooled Variance	15.28287385	
Hypothesized Mean Difference	0	
df	35	
t Stat	-2.424045545	
P(T<=t) one-tail	0.010326784	
t Critical one-tail	1.689572458	
P(T<=t) two-tail	0.020653567	
t Critical two-tail	2.030107928	

Table 6.9: T-test results for skills performance

	Variable 1	*Variable 2*
Mean	56.72222222	57.47368421
Variance	87.27124183	39.37426901
Observations	18	19
Pooled Variance	62.63851295	
Hypothesized Mean Difference	0	
Df	35	
t Stat	-0.288667897	
P(T<=t) one-tail	0.387269175	
t Critical one-tail	1.689572458	
P(T<=t) two-tail	0.774538351	
t Critical two-tail	2.030107928	

- Dislocated learners have achieved higher marks than co-located ones for the theory assessment.
- The difference in performance between dislocated and co-located results seems to be more pronounced for the lower category but less marked for the upper category.

Table 6.10 summarizes the students' performance for the theory test (average value in bold; range of values in italics and brackets). In relation to the skills performance results when divided into three equal-interval categories, the main findings are as follows:

- Dislocated learners have achieved equal marks to the co-located learners in the skills assessment performance.
- In terms of skills performance there seems to be no pronounced difference for all three categories (lower, middle and upper).

Table 6.11 presents a summary of learners performance for the skill test (average values are in bold, and the range of values are in italics and brackets).

Table 6.10: Summary of the learners' performance for the theory test

	Lower	Middle	Upper
Co-located	**15.5** *(13-18)*	**20** *(18-21)*	**24.8** *(22-30)*
Dislocated	**19.7** *(16-22)*	**23** *(22-24)*	**26.5** *(26-29)*

Table 6.11: Summary of the learners' performance for the skill test

	Lower	Middle	Upper
Co-Located	**50.8** *(40-56)*	**58** *(56-61)*	**63.5** *(62-67)*
Dislocated	**46.2** *(38-55)*	**58.5** *(55-61)*	**65.5** *(61-68)*

As already discussed in the Introduction, the objective of the promotion research work was the development of a novel and more effective system for distributed refrigeration engineering education. Our major assumption was that the novel system should blend various enablers, and should consider the personal characteristic and learning style of the individual learners. The prototype design uses computer supported game engine technology to provide location independent comprehension and procedural skills learning for refrigeration engineering. Blending technological, cognitive and social enablers is almost intuitive to the digital user [12]. We wanted to confirm if computer aided teaching can enable dislocated learners meet the same objectives and achieve the same performance as co-located learners.

Based on our dataset, we can clearly see that the theory performance of the dislocated learners is slightly better across all three ranges than that of the co-located results. Table 6.12 summarises the contact learning hours for each of the two groups. From this we can see that the contact hours for tutor to learner (assisted learning) was rather different. Numerically, there were 40 contact hours for the co-located groups, and 16 contact hours for the dislocated groups. What the table does not show is the fact that the dislocated learners had access to the learning material and each other 24 hours a day via the website (unassisted learning). Perhaps this is a contributing factor to the overall improved theory performance.

On the other hand in relation to the procedural skill performance of the dislocated learner we must note that at the lower level of the performance results for the dislocated learner underperforms compared to the co-located counterpart. Looking closer at the middle and upper levels of skills performance we note an equal (middle level) to higher performance (upper level) for the dislocated learners. What the statistics do show is that the prototype has gone some way to support dislocated learners achieve equivalent performance results of their co-located peers.

In Chapter 3, we presented RC2 (influential factors and causalities). From our initial research we considered the influential factor that cognitive enablers have for both educator and learner

Table 6.12: Summary of the contact learning hours per control group type

	Co-located	Dis-located
Real Classroom Hours	40	8
Virtual Classroom Hours	0	8
Assessment Hours	6	6

during face to face teaching. Based on this we concluded that if the dis-located learner experience is to be enriched, there is a need for an enabler that can determine the level of comprehension of the learners, in order to adapt online delivery accordingly. The results of both the theory experiments and the skills experiments appear to be in line with evidence presented in Chapter 3, namely, as according to Ally, not any particular type of technology can improve learning [13]. As discussed in Chapter 3, Clarke contended that while technology is recognised as an effective and efficient means of delivering education, it is merely a medium used to provide instruction and does not improve learning [14]. Our prototype uses instructional strategy, setting challenging activities, to force learners to develop their cognitive abilities as evident from our theory performance tests [15]. Our skills performance data requires future investigation into the knowledge gap between learning online procedural skills by point and click (VR environment) and transferring this knowledge to the real world screw and unscrew with real world tools such as a spanner.

The concept of the WBS-LS prototype has been based on blending of technological, cognitive and social enablers. Their integration is a natural phenomenon. The level and format may also vary as it is very much dependent on the human user's perception and psychological state of mind. The main function of the enablers is to (i) motivate students, (ii) provide perceived usefulness, and (iii) ensure rich knowledge transfer. The data indicates that the WBS-LS porotype has managed to achieve these functions. All learners, are seen as individuals with different perceptions and expectations. Therefore we propose that human diversity must be a central consideration and should be accounted for when developing any form of online teaching and learning methodologies and tools.

6.3 Investigation of the satisfaction of the learners

In the framework of the learners satisfaction test, each learner was presented with an online (survey) questionnaire as the basis of the user evaluation.

Question number 1. Asked about the type of hardware device used to log onto the prototype WBS-LS host web site. In response to this question, 50% wrote down the answer as laptop. 14.3% used a tablet device and 35.7% used a desktop. There was no recorded answer relating to the use of a mobile phone (Figure 6.10).

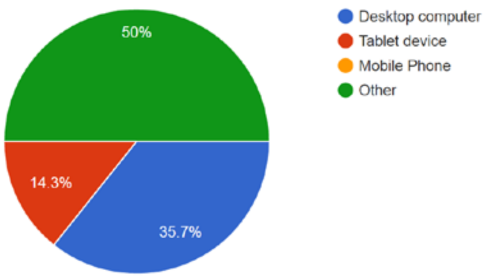


Figure 6.10: Response type of hardware used

Question number 2. Using a scale of 1 (strongly disagree) to 5 (strongly agree) the learners were asked to rate the interface design. The largest, 42.9% participants neither agreed nor disagreed (score 3), that the interface design produced intuitive interactions using their chosen device. The remaining ratings were; 0% at a 1 score, 14.3% at a 2 score and 21.4% at a 4 and 5 score (Figure 6.11).

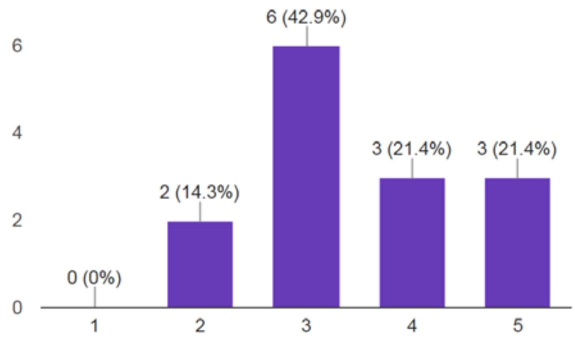


Figure 6.11: Rated response to interface design

Question number 3. When asked if Logging onto the web-site and if downloading content was straight forward, Figure 6.12 illustrates how the learners ranked the WBS-LS prototype in this regard. The ranking ranged from 1 (disagree strongly) to 5 (agree strongly).

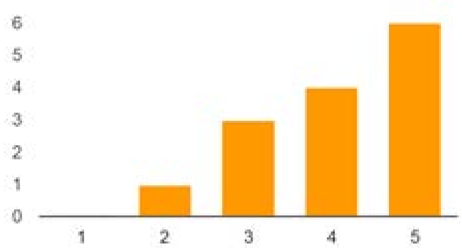


Figure 6.12 Learners' satisfaction ranking for logging on to the WBS-LS prototype web page

Question number 4. The process for downloading web content was identified as very unsatisfactory by 7.1%, somewhat satisfactory by 7.1%, about average 50%, and very satisfactory by the largest group at 35.7%. (Figure 6.13).

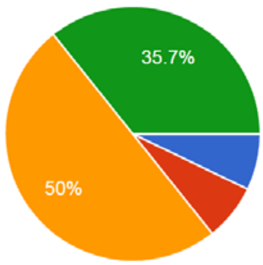


Figure 6.13: Learners' satisfaction response to ease of downloading web content

Question number 5. The learners were asked to rate their reaction to the overall website. The range was from terrible at 0%, wonderful at 7.1% to frustrating at 14.3%, the highest at satisfactory was 71.4% and stimulating at 7.1% (Figure 6.14).

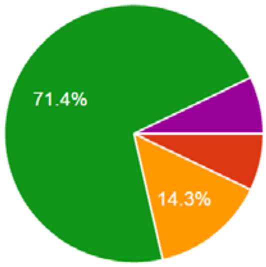


Figure 6.14: Learners' rating of their overall impression of the WBS-LS prototype website

Question number 6. The 3D models and menu buttons on the refrigeration simulator screen were Very Clear57.1%, confusing 7.1%, Hard to read at 0%, Organised logically at 35.7%. (Figure 6.15)

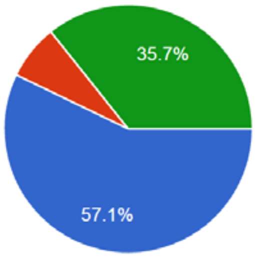


Figure 6.15: Learners' satisfaction rating of the VR models menu interface

Question number 7. The position of Messages on the screen were 'Consistent' (option 1) scored 57.1%, 'inconsistent' (option 2), 7.1%, 'clear', 28.6% and 'confusing' 0% (Figure 6.16).

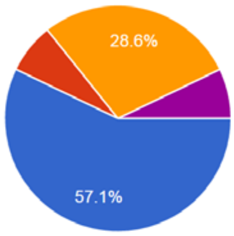


Figure 6.16: Learners' satisfaction rating for how messages were positioned

Question number 8. Learning to operate the refrigeration simulator was found to be easy by 85.7% and difficult by 7.1% (Figure 6.17.

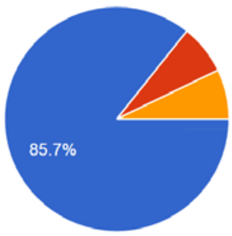


Figure 6.17: Learners' satisfaction rating with learning how to operate the refrigeration VR simulation equipment

Question number 9. When asked if the system design catered for experienced and inexperienced user needs 57% felt always, 7% felt never, somewhat at 28.6% and other at 7.1%

(Figure 6.18).

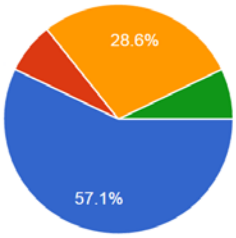


Figure 6.18: User satisfaction rating with WBS-LS design for both experienced and in experienced digital users

Question number 10. In measuring the realness of how the VR models operate improved your knowledge and understanding of refrigeration strongly disagree were at 0%, score 2 at 0%, score 3 at 28.6%, score 4 at 42.9% and strongly agree (score 5) at 28.6% (Figure 6.19).

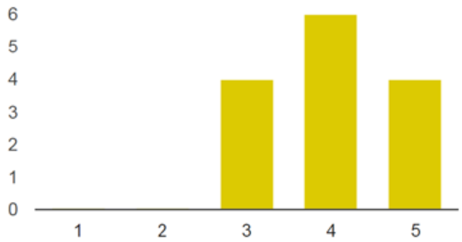


Figure 6.19: Overall ranking of VR models visual and operational realness

Question number 11.When asked if using the WBS-LS as a learning and teaching tool, enabled in depth understanding of refrigeration principles no one strongly disagreed, 21% strongly agreed (score 5) and the remainder were ranged between 1(s/disagree)-5 (s/agree), score 2 at 7.1%, score 3 at 28.6% and score 4 at 42.9% (Figure 6.20)

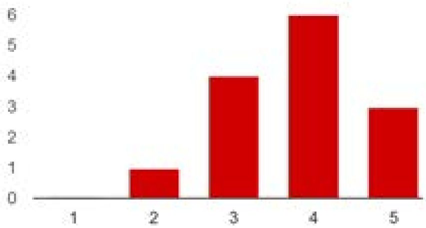


Figure 6.20: The WBS-LS ability to disseminate refrigeration knowledge

Question number 12. The learners were asked to rate the level to which they agreed or not with the statement that the system enhanced their ability to problem solve. Figure 6.21 illustrates that 42.9% agreed while 1% disagreed.

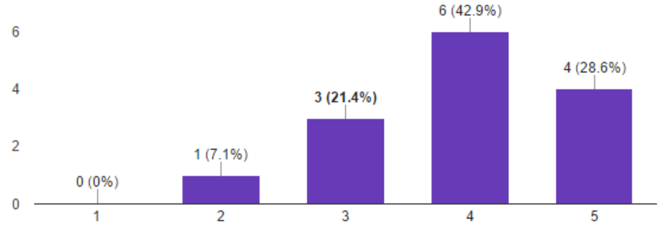


Figure 6.21: Learner's satisfaction rating with the WBS-LS as a tool to enhance problem solving ability

Question number 13. The learners were asked to rate if the ability to communicate via a conference call helped to promote an overall sense of community. Interestingly 42% remained neutral by either just moderately agreeing or dis-agreeing with this statement (Figure 6.22).

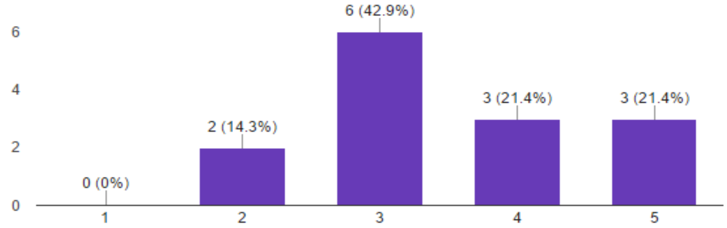


Figure 6.22: Learners' satisfaction rating of WBS-LS as means to enhance an overall sense of remote learning community

Question number 14. Stated that this sense of created community fosters human to human online interaction. 1% disagreed, 50% responded as neutral (either moderately agree or disagree) and 21.4% agreed or strongly agreed (Figure 6.23).

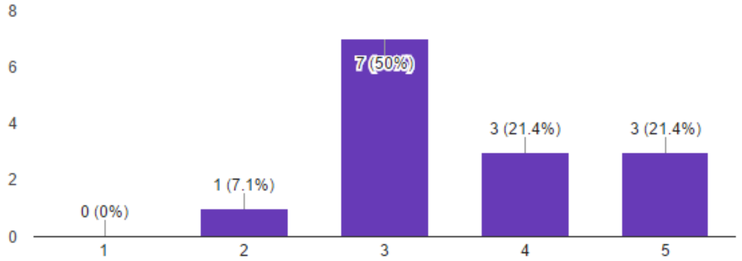


Figure 6.23: Learners' response to the concept of an online community fostering human to human online interaction

Question number 15. Learners were asked to rate their satisfaction with the ease in which they were able to complete the assigned tasks (procedural skills Table 6.1) using the WBS-LS. Figure 6.24 illustrates the responses. Some 35% of respondents agreed and a further 28.6% strongly agreed (Figure 6.24).

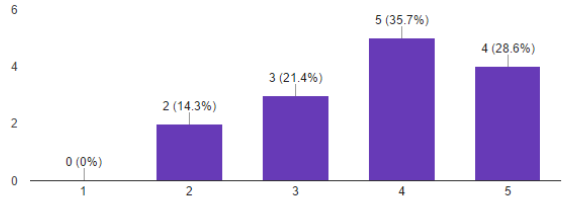


Figure 6.24: Learners' response to the ease of use of the WBS-LS to complete procedural skills

Question 16. Overall satisfaction with the support information in the form of notes, video tutorials and real time communication via conference call and text facilities were rated: 50% agree and a further 28.6% strongly agreed. 14.3% remained neutral and 7.1% disagreed (Figure 6.25).

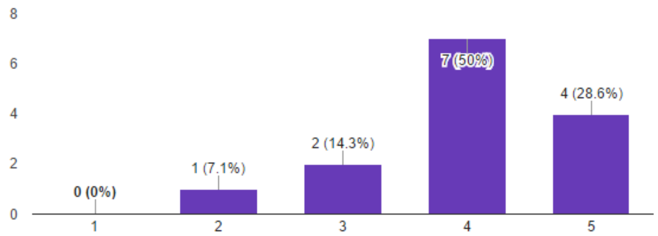


Figure 6.25: Satisfaction rating with WBS-LS pedagogical supports

Question 17. The statement was: 'I can easily learn how to use the WBS-LS without instruction'. Figure 6.26 shows the learners' response which was rated on a scale; always, never and other. 92.9% claim always while 7.1% claim never.

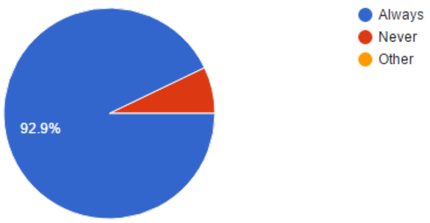


Figure 6.26: Learners' response to the ease of self-learning how to use the WBS-LS

Question 18. There was a statement that the WBS-LS gives more control over how an individual learns. Again using the scale; always, never and other, 92.9% state 'always' (Figure 6.27).

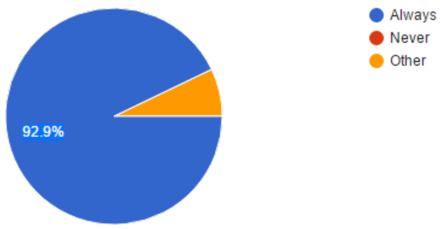


Figure 6.27: Learners' response to how the WBS-LS gives more control; over personal learning

Question 19. Please describe any positive or negative aspects about the WBS-LS. Six respondents wrote the following answers:

- "To be able to play back the lecture in my own time is one positive of web-based learning. The only negative would be that sometimes the class would be interrupted with a bad connection, but this inevitable and was dealt with promptly."
- "I didn't use it much because whenever I did it caused the computer to overheat. When I did use it I found it hard to get it to do what I wanted it to do, but as I said I did not use it that much so hard to rate."
- "Using the mouse was fiddly"
- "Easy to learn"
- "System idea is good but the graphics were slow to upload on my PC"
- "It has its purpose"

Question 20. Do you have any suggestions for improving the web-based system?

Five respondents wrote:

- No
- No
- No
- No suggestions, sorry
- Would it be possible to have 2 levels of learning, experienced and inexperienced?

6.4 Conclusion about the impact

6.4.1 Reflections on the achievements

We set out at the beginning of this chapter to validate if the prototype implementation could meet real life requirements and contexts and to express the utility of the VR system in terms of indicators and tangible measures. The data presented in Tables 6.10 and 6.11 indicated how the dis-located learners performed in comparison to their co-located counterparts. The quantitative statistical analyses proved that the prototype motivated dis-located learners to perform equally at the lower spectrum of results and slightly better than, at the middle to higher level of the results spectrum, than their co-located counterparts.

The qualitative results from the dis-located learner satisfaction survey helped us understand if blending of technological, cognitive and social enablers had contributed to this motivational impact. The responses received from the learners concerning questions relating to the effect of technological enablers for the large part were very positive, for example concerning (i) logging on, (ii) downloading, (iii) graphics and 3D models, and (iv) navigation. The aspects in which the technological enablers may be further improved were such as: (i) interface design to promote intuitive interaction, (ii) bandwidth requirements especially if the use of the system is intended for mobile networks, and (iii) the use of the 'point and click' mouse feature. The data extracted from the responses related to the used cognitive enablers were positive In the following aspects:

- Positioning of the prompt messages for instructional guidance
- The ease at which one could learn to operate the 3D refrigeration systems

- The realness in which the VR models operated
- The prototypes ability as a learning tool to enhance the problem solving abilities for the individuals.
- The ability to play back lecturers anytime anywhere
- The ease of downloading learning material and the availability of supporting material

At the same time, it was learnt that the use of the main cognitive enablers could be improved in future research from two aspects: (i) consideration must be given to the psychological reasons of the poorly performing learners, and (ii) investigation of the reasons of poor performance of some of the dis-located learners (if it could be traced back to personal issues or issues related to the implementation of particular cognitive enablers in the system). Note that, from a research perspective, this may be studied buy reverting the roles of the poorly performing dis-located learners from being dis-located to being co-located, and checking their performance in the new position.

Concerning the impacts of the used social enablers, the main positive responses were as follows: It was found useful (i) to have the conference call facility within the system, and to able to identify if other members of the group were online at the same time, and (ii) to have control over their own learning and a choice of where to turn to for obtaining support (other source/learners or tutors). The main areas for further improvement in relation to the effectiveness of the social enablers included in the prototype were: (a) a means to enhance the sense of community for remote learners, and possessing the ability to foster human to human online interactions.

In summary, as demonstrated by the prototype WBS-LS, the observed impact of the blended technological, cognitive and social enablers was that the system was able to motivate dis-located students to perform equally well in comparison with the counterpart co-located peers. This is an important confirmation since our aspiration was to provide a learning environment that (i) permits engagement, (ii) allows for individualism, (iii) caters for a varied learning pace, and (iv) provides instant access to large amounts of information. In addition the results underpin that another objective of the whole study, namely creating a ‘design framework’ for a web-based visual learning and teaching environment, which provides interactive animations of real world, procedural construction engineering skills, was also attained.

Concerning the outcome of the usability survey, 42.9% (almost half) of the sample subjects gave a neutral rating for the interface design of the prototype system. This is of significance because our goal was to provide a user interface menu that was intuitive and almost instinctual by design. The neutral responses combined with 14% disagree rating oblige us to conclude that the interface design do require further enhancement. However, before making any changes, we need to evaluate what level of digital knowledge the individual learners had before they began to use the prototype system, and how much they completed the objectives of the learning scenarios. It may in fact be the case that the proposed interface has the capability to train the learner to interact with the prototype system in a seemingly natural way [16]. However, due to practical constraints, the promotion research could not extend to a comprehensive review of the intuitiveness of the interface design for such a complex tool as the prototype system and therefore shall have to be deferred to future research. It was beneficial to build on the results of the commercial game industry at the development of the prototype. We could learn from their experience concerning the use of real world learning scenarios. These were considered as part of our blended enabler design. In accordance with the rules of designing successful computer games, we managed to;

- Use an efficient software, which provided visually convincing graphics and real world procedural animations,
- Incorporate a networking service, which provided sufficiently reliable ubiquitous connectivity. (This was important since it was experienced that rural areas with low bandwidth infrastructure made the communications complicated and frustrated the learners.)
- Provide a professional finish in terms of imaging and modelling situations.

In the course of the system development process, we identified four main tasks in order to achieve the above by:

- replication of real world interactions of learners with tutors and learners with learners as captured by video-recordings and visuals in the real world in the web-based VR learning space,
- simulation of real world learning scenarios in a web-based VR learning space
- enabling bi-lateral communication to facilitate peer to peer community learning and encourage pervasive learning, and
- availing both synchronous and asynchronous tutorials.

The data obtained by the usability survey showed that the prototype of the web-based stimulating learning system was only satisfactory for the 71.4% of the learners. However 14.3% of the learners was frustrated by the way of using the prototype, and only 7.1% found it to be really stimulating. The rest did not respond. Looking deeper at the reasons of being just partially or not at all satisfied, we found that partly the hardware and partly the high variation in the digital literacy might be the reasons. Therefore, we concluded that the next version of the prototype should be based on the outcome of further research in the use of 'sandboxing' [17]. By using 'sandboxing' we will be able to provide more opportunity for personal customization of the contents of standard files, while not influencing the content of the original source file. By providing learners with the option of moving around freely within the VR-based learning environment and to execute untested code without violating the security of the operating system, offers a higher level of autonomy and brings the learner one step closer to the pervasive learning environment [18]. However, there is an obvious need for further research into the effectiveness of such a higher level autonomy with regards to the reliability and quality learning outcomes.

It was challenging to test the impact of the software platform of the prototype WBS-LS on the understanding of learners [19]. In this context we can refer back to the literature. Rahimi, et alias discussed the shift towards proactive and context-sensitive personal learning environments [20]. This shift entails a change in the role of the learners concerning the control of the learning process. Based on the results of the learners satisfaction survey we found that not all learners were ready to take control of their own learning and remained reliant on instruction. The prototype system equipped with technological, cognitive and social enablers offered them a different experience to what they had been traditionally exposed to. The historical learning experience of learners can determine the potential performance and the extent of how much they can perform better. potential for future learning success. As a reflection we can argue that this needs to be paid attention, but it is unclear how to manage this issue in the context of an advanced learning system assuming computer literacy and digital attitude. Everyday societal technology is pushing learners towards smart devices, but not necessary towards sophisticated solutions. The only way out from this situation seems to be a daily exposure to such devices, which will ultimately give the autonomy to learners to develop personalised ‘learning on the go’ knowledge environments [21].

6.4.2 Possible enhancements based on the utility tests

Below we summarise those immediate enhancements opportunities that were revealed in light of the results of the utility tests (deficiencies and improvements) related to skill and knowledge improvement of the learners. Other long term enhancement opportunities will be discussed in Sub-section 6.4.3.

Enhancement 1

In its current form, the graphical user interface (GUI) limits the opportunity of expanding its functionality. For example the number of learning scenario content needs expansion. The current prototype is limited to nine fault finding or troubleshooting learning scenarios. To expand beyond this number requires upgrading of the current GUI. The prototype menu system is cluttered with too many options. Adding more learning scenarios requires increasing the menu options thus further cluttering up the screen. The solution could be as simple as changing the existing menu font size to ensure the menu takes up less screen space. Another alternative is to opt for responsive menu or consider the use of radial menu system.

Enhancement 2

The log in sequence generates a handful of variables such as floating numbers or Boolean values. The number of learners online at any given time creates multiple variables specific to their needs. The deficiency of the current prototype is that all these metadata are being collected and forwarded to all learners online at the same time. This in turn creates a history of events which stay in the cloud server building up a story of messages ready to send to each local server of the concurrent learners. Poor Internet transfer quality reduces the bandwidth. This information lag may cause the local game file to crash and or become disconnected from the network. A possible solution to this problem is to filter metadata by introducing a priority optimisation script. The script can be equipped with the ability of identifying priority variables, keeping updating to a minimum. Another solution is to write a script to handle messages that have been delayed at any given local server to be oriented to the cloud server for storage until the local server has regained the capability of retrieving same from the internet.

Enhancement 3

Real-time communication/live streaming optimisation is needed to enhance the fluidity of learner experience. The only way to ensure uninterrupted connectivity is to have sufficient internet quality. This experience goes beyond the competence of the prototype learning system. On the other hand this has to do with quality of education thus we used the option of Skype™. In fact during these live online meetings we reverted to using Skype™ as our voice and visual communication means on occasions when the number of learners with poor quality Internet bandwidth was above the norm,. This meant that we ran our WBS-LS game file offline mode and used the share screen feature built into skype when we wanted to demonstrate the learning visuals. Skype^{TM} managed to keep those with poor internet bandwidth connected for the two hour learning session and the share screen option was an acceptable substitute for the provision of a shared learning experience.

Enhancement 4

The current prototype uses one single level representation for visual perception. Thus, this does not use the visualisation potential of high end computer hardware. On the other hand, in the case of lower end hardware devices, this single level representation reduces the visual imaging performance. Using one level of non-adjustable resolution in terms of both details (polygons) of the 3D models and the texture detail produces two different effects on high end and low end hardware devices. In the case of the former it does not utilise visual imaging capacities which are available. Conversely in the case of the latter it overloads the computing performance of the hardware devices.

An example is mobile hardware running under Android operating system which offers a wide range of graphical capacities. For the low end hardware devices it scales down the models to have a lower number of polygons and smaller texture image file in comparison to those used in the high end devices. Thus, the solution in the case of the prototype learning system is to introduce an optimisation technique known levels of detail (LOD). This facilitates producing 3D models and texture in accordance with the available computing power or CPU. This adaptation provides balanced access for learners who either have low end or high end learning devices. This enhancement can be realized by developing multiple LOD models/learning objects and having in place a script that can recognise the hardware capacity and download the relevant game file.

Enhancement 5

Learners interact with the WBS-LS VR environment as they progress through the various faults or multiple choice questions. The information is stored by the local server up until the point when a learner *'log off'*. Upon initiation of the log off sequence the locally stored information is uploaded to the cloud data storage server. The problem during times of low quality internet is the data which is unique to the individual learner can fail to upload and become lost. This entails the need to replace the currently used wordpress^{TM} software with other software which provide opportunities to prevent the loss of data and maintain the efficiency of the logging off sequence. The optimal solution can be to use a scripting language such as PHP to read and write script to and from a data base. Using the PHP for this log off function would have a positive effect on learner experience by shortening their log on/off times and by simplifying the data structure which is transmitted across the involved computing system. Using one file type would be an ideal solution. However because of the commercial distribution platforms, there is a requirement for multiple file types.

Enhancement 6

It has been observed during the utility validation test experiments that different learners were already accustomed to the use of different operational service platforms. Rather than leaving the problem of making the WBS-LS compatible with multiple service platforms and because of the severity of this problem, a future solution could be in the form of promising software such as WEBGL^{TM} which is showing signs of its ability to enhance cross platform compatibility. In addition this application programming interface can enable 3D/2D interacting rendering without a need for additional plug in software.

It seems necessary to further investigate the capability that WEBGL™ offers for the cross platform software updating application and that may contribute to the avoidance of software update compatibility issues. The advantage of WEBGL™ is that it is an open source and more comprehensible than Google Play™ or iTunes™. In the case of multiple platforms the changes should be completed for multiplatform and for multiple variations.

Enhancement 7

It was validated by the user satisfaction survey, but also underpinned by observation of the programmer that certain local interface operation such as the cursor and tool utilisation did not provide sufficiently intuitive feedback to the learner about actions that they wanted to take. The appearance of the imperfections was even more observable in the case of feedback about the virtual tool they were actually using. Both issues could be efficiently addressed using 3D representation of the virtual tool in use which could be attached to the cursor and follow its movements. Alternatively it could also be signified by the GUI symbol which is displayed on the screen. This would contribute to the sense of presence when interacting with the WBS-LS.

6.4.3 Long term enhancements

Below we give attention to those not immediate enhancements opportunities which could improve the learning system from a utility and efficiency perspective. Towards this end certain deficiencies have been identified. As the current smart devices are moving towards speech based technology means, we too have to move in this direction. This will require a change of the prototype GUI to an audio interface and retina eye tracking. We absorbed a problem with the accessibility of our system which we discovered goes beyond further adaptations.

The main issue is if the learners are familiar with different working platforms then there is a task on setting up our WBS-LS to become compatible with multi service platform software. However, there is no evidence which would show that a multiple service platform changeability has an effect on how less the digital savvy is. The learners' performance is comparable with those learners with higher level of digital literacy. The level of semantics for dealing with leaners and learning materials should be increased in order to enhance the WBS-LS. Currently, the lowest levels of smartness is considering ontology aided education. Through the ontologies, the system and the learner communities of practice can have more semantically rich and contextualized forms of digital education. Ontology-aided education can be seen as the next possible iteration of the WBS-LS.

6.5 Future considerations

Leaving behind traditional classroom environments raises the challenge for learners and educators to reflect on how new technology based learning systems affect their habit formed traits on (i) how to think, (ii) create, (iii) analyse, (iv) evaluate, (v) transfer and (vi) collaborate purposefully in digital ones. Part of our prototype design involved using open source resources, which can be integrated into the dis-located individuals' personal devices [22]. Future research will consider if the prototype can be extended to include a logic stimulation and monitoring module. The aspiration is to develop the prototype system as one which understands the context, builds awareness and adapts itself to the expectations/conditions in a smart way. This means a motion towards the implementation of an informing cyber-physical system.

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Chapter 7

Conclusions and future work

7.1 Reflections on the overall findings

This promotion research describes, as a result of scientific cycles, how an educator with low levels of computer programming ability, aggregated knowledge about VR/AR CEE applications, conceptualised a web-based design for an enabler centred learning system, built a web-based 3D VR/AR technology learning system environment, and implemented it to validate it's utility as a distant learning stimulation learning system for educating dis-located construction engineering learners. To maintain a focus we applied five research cycles as follows; (i) the state of the art concerning the application of VR/AR technologies in CEE, (ii) the influential factors and causalities, (iii) conceptualisation of the design, (iv) the validation of a testable prototype and (v) the implementation of a prototype in real life context.

During the experimental realisation of this promotional research, three domains of interest were addressed; (i) system development, (ii) way of learning and (iii) didactic objectives. The continuous rapid growth of VR/AR technology has produced multiple freeware open source software applications resulting in accessibility for a greater majority.

7.1.1 Research cycle 1: State of the art of screen-based CEE VR/AR technology development

The main objective for the first research cycle was to aggregate knowledge about the primary insights in the general occurrence of VR/AR technological growth and usage in the field of CEE. The guiding questions were:

- What are the cutting edge application of VR/AR screen-based learning environments in CEE and what are the detectable knowledge gaps in the educational usability design of these applications?
- Are the design and implementation of these identified applications fit for purpose to provide dis-located construction engineering students with a similar educational experience as there co-located counterparts?

The main technological findings of RC1 can be summarised as follows:

1. *Researchers have been investigating the concept of using computer generated simulation (CGS) for a number of decades. In spite of this there still remains a number of issues that remain unresolved with regard to screen-based VR/AR learning environments.*

Issues such as technical, physical, physiological, social and measurement concerning the state of 'presence' when learners interact with screen-based VR/AR learning environments, remain unanswered [1]. An underpinning theory to develop successful screen-based VR/AR simulation learning environments is the theory of 'presence' [14] [2]. Ongoing research in a number of scientific fields have yet to produce a definitive design methodology to guarantee the creation of 'presence' for leaners interacting with a screen-based VR/AR learning environment. In fact it must be noted that to date, there is no clear definition on whether or not a learner's state of presence when interacting with a screen-based VR/AR learning environment has an effect on the eventual knowledge gain and improved performance attained by the individuals.

2. *It is now possible for novice programmers to simulate real life scenarios in AR/VR screen-based computer generated simulation environments*

In the search for CEE related screen-based simulated learning environments a number of simulation engines such as Blender™ [3], TrueVision3D™ [4], Unreal tournament™ [5] Webots™ [6] Unity™ [7] and Matlab™ [8] were unveiled by researchers as suitable tools to develop 3D screen-based VR/AR learning environments. Although all of these screen-based simulations had redeeming features, they all required further iterations before they could be deemed suitable as a distant learning environment for CEE in the context of this research promotion.

7.1.2 Developments in the way of learning for CEE digital learners

The amount of literature referring to the use of VR/AR screen-based learning environments to enhance learning in the classroom is vast. However there is an equal amount of evidence which proves that social, collaborative and shared experiences are contributing equally to learning outside the classroom, a term coined 'experiential learning'. Cross refers to this as 'natural learning', that is learning from others as and when you feel the need to [9]. The main findings from RC1 relating to the way of learning for the digital learner are summarised as follows:

3. *Digital learners use technology as a foundation base for everything they do.*

Much of the literature referring to the digital generation draws our attention to the positive effect technology is having over the quality of modern life [10]. In fact the evidence suggests it is the technology that enables this generation to interact with and commit to multiple activities and tasks over a normal working/social day [11].

4, *Digital learners are natural multitaskers and use multiple software platforms to interact between the real and the digital world.*

There are numerous examples in the literature highlighting cases of the 'digital generation' use of technology ranging from extravagant practice to the everyday mundane. The 'digital generation' way of life now involves the use of handheld mobile devices. They are incorporating these devices with multiple digital media software and switching between activities such as responding to a text message or other such media, while watching TV, sending a tweet/email, listening to music and ordering cinema/concert tickets.

7.1.3 The didactic objectives of the CEE digital learner

As stated above the digital generation way of life has become natural to them and therefore they instinctually revert to their handheld mobile device or other type of hardware when they require new knowledge or a news update. Therefore we can deduce:

5. *Digital learners read web page content and digital social media content more frequently than they read from hard copy text media and books*

The commercial world have picked up on this new way of life and as a result actively promote their product or service through the means of digital media. It is considered unusual for a commercial entity not to have some form of digital presence and as a minimum a website or a social media (such as Facebook^{TM}) account. The digital video game industry are considered as industry leaders when it comes to meeting the needs of the digital generation. This promotion research provided evidence which suggests that;

6. *AR/VR can now promote a high level of interactivity both through social and cognitive based virtual encounters.*

In addition to the video game commercial activity, is the growth of game developer communities who meet regular online to assist each other and to offer useful consumer suggestions to the commercial or open source software developer. The result of which has led to game development software with easy to follow instructions and 'drag and drop' type interface to assist with amateur game development activities.

7.1.4 Research cycle 2: The influential factors and causalities of game based technological learning environments

The second research cycle aimed at unearthing data which specifically investigates the influence and limitations of the CGS screen-based software packages, as identified in the survey from chapter two. The key question associated with cognitive and technological enablers in this research cycle was:

7. *What are the key factors influencing the introduction of screen-based VR/AR learning environments that produce detailed cognitive stimulation of procedural activities in CEE?*

The reasons for the slow uptake of screen-based VR/AR environments for the dissemination of CEE is still unconfirmed and remains exploratory. According to Kukulska-Hume et alias in general the stumbling blocks for AR/VR CGS screen-based learning environments which fail to reach their full educational potential tends to be financial on the side of the learning institute or technical on the side of the educator and or learner [12]. Daly exposure to handheld mobile technology and their associated software platforms allows us to conclude:

8. *With mobile technology becoming more commonplace the integration of cognitive enablers with technological ones is being perceived as a seemingly less complex in design and more of a natural phenomenon.*

7.1.5 Research cycle 2: The influential factors and causalities of the way of learning with VR/AR screen-based learning environments

Screen-based VR/AR learning environment software and in particular those adapted for use with mobile hardware technology platforms have introduced trends such as pervasive learning, situated learning, context awareness, ubiquitous networks, media richness, interactive and intelligent reactions into CEE [12]. The literature provides case study examples in the context of CEE, which are typically presented as practice-based research. In conclusion the influential factors and causalities of screen-based VR/AR concerning the way of learning for CEE is as follows:

9. *Design for learning with screen-based VR/AR learning environments should be based on shared domain-specific philosophy according to the needs of the learner.*
10. *Procedural information can be continuously updated by adding content and technology.*
11. *Commercially designed VR/AR game based environments with fictional real world scenario context, excel at engagement, and stimulates cognitive skills.*

7.1.6 Research cycle 2: The influential factors and causalities of the didactic objectives of VR/AR screen-based learning environments for CEE

Typical teaching and learning support, as well as peer support, tends to be centred around: (i) content, (ii) communication, and (iii) learning activities [13]. The aim is to provide a learning environment that is based on a technological screen-based learning system that permits (i) engagement with a subject matter, (ii) allows for individualism, (iii) a varied work pace and (iv) provision for student access to material. In addition, learning activities are learner centred, and situated learning theory is a key factor with regards to CEE. The conclusions referring to influencing factors and causalities of didactic objectives were as follows:

12. *The content of the learning programme should have no predetermined limits or authoring rights.*
13. *The students must be encouraged to construct knowledge in accordance with their own learning style.*
14. *There are a number of learning theories associated with CEE and these should be identified and applied according to context.*

7.1.7 Research cycle 3: Conceptualisation of the technological design

The focus was on the conceptualisation of the type and number of technological enablers that could have the ability to address the findings from the previous research cycles. The findings included the following:

15. *Advanced VR/AR simulation packages have the ability to enhance traditional training methods and learner experience once it is used as part of the learning system design as opposed to being used because of its perceived capabilities.*

7.1.8 Research cycle 3: Conceptualisation of the way of learning

The developed world's future economy is grounded on knowledge. Higher education providers strongly believe that they must change in order to produce a new level of innovative undergraduates. The result of this is:

16. *Realistic and relevant virtual simulation requires careful consideration of numerous and complex behaviours.*

7.1.9 Research cycle 3: Conceptualisation of didactic objectives

The conceptualised didactic objective was to develop (i) flexible, (ii) innovative and (iii) responsive screen-based VR/AR learning environment. The concept of the environment is in keeping with the reality of a knowledge economy which has people (i) mobile, (ii) embracing change and (iii) partaking in lifelong learning. The findings can be summarised as:

17. *The learning pedagogical support needs to ensure the cognitive stimulation and perceptive immersion is created.*

7.1.10 Research cycle 4: Validation of the prototype learning systems technological design

Our focus was on the development and validation of the testable prototype. The prototype was designed and tested to establish tangible values:

18. *The prototype design addressed the identified technological challenges of self-managed*

socialised on-line learning.

It offered a student-centred knowledge and skills acquisition approach. Central to the prototype design was the blended enabler framework which assisted learners to develop problem-solving and higher level thinking skills when presented with scenario learning.

7.1.11 Research cycle 4: Validation of the digital learning system prototype for way of learning

The complex set of learning scenarios had multiple fictional stories. The fictional applications for the WBS-LS was established through the use of credible stories in the form of operating malfunctions of real world refrigeration equipment. The second validation question we considered was:

19. *Does the prototype design cater for the identified styles of learning challenges of the diverse human learners in the field of CEE?*

Because of the diversity and complexity how individuals learn the learning scenarios were the catalysis to produce a representative example of this diversity and produce the data which could be evaluated as learner performance.

7.1.12 Research Cycle 4: Validation of the learning system prototype didactic objectives

Didactic validation required us to bench mark learner performance against the performance of the co-located learners. The main conceptual functions of this prototype was presented to an expert group for validation. The evaluation combined heuristic evaluation with the benefits of a cognitive walkthrough. The key question for this group of experts was:

20. *Should educators attempt to make the technology fit with traditional teaching methods rather that first trying to understand how technology works and how it can enhance teaching and learning methods if didactic instruction to be applied is designed first?*

The focus group of experts placed a stronger emphasis on identifying what makes learning and teaching technique more effective. They identified their expectation for digital learning environments as a means to effectively translate real world learning and teaching techniques into the virtual learning environment. The blended enablers-based prototype was reconfigured to meet the expectations of digitally-experienced and digitally-intuitive learners based on the data compiled at the expert focus group session.

7.1.13 Research cycle 5: Implementation of the technological learning system.

The WBS-LS system included more than just the latest technologies and system operation architectures. Actually, it blended various technological and non-technological learning enablers, and considers the personal characteristic and learning style of the individual and community of user’s. The literature presented the strength of the technological enablers and opened the possibility to explore how to design a web-based educational system that blends technological, cognitive and social enablers.

7.1.14 Research cycle 5: Implementation of the way of leaning

There is a reason why our research addressed the issue of educational enablers in a broader context. Rather than focusing only on the technological ones, we identified complementing enablers, which effectively engage digitally literate students in problem-driven learning processes. While considering their individual needs, capabilities and circumstances. A crucial lesson from the implementation of the multi-enabler based system was the realisation that digital learners are not specifically about the technology, but are more about the activities and experience.

7.1.15 Research cycle 5: Implementation of the didactic objectives

This research discovered that there is recognition and acceptance for the need to build a WBS-LS incorporating a multi enabler based design framework. As a visual learning and teaching aid the system design provides the educator with realistic type working models - making it easier to describe and explain subject matter. This design framework has the capacity to continue to evolve for many years without the need for educator and learners becoming expert computer programmers.

7.1.16 System development

Through our inductive analysis of the emerging data we developed a theoretical hypothesis relating to the conceptual design of a blended enabler design architecture. As a result of the time and energy digital learners devote to playing screen-based video games it seemed appropriate to explore the power this technology had to motivate and engage learners. Chapter 3 (RC2) describes the influential factors applied to the development of a WBS-LS to use for the delivery of a skills and knowledge based module in refrigeration engineering. This module had clear aims, objectives and defined learning outcomes. Figure 7.1 shows the workflow steps completed as a novice programmer to find, design, build, test and validate a workable prototype WBS-LS for utility testing.

The individual literature studies discussed in Chapter 2 (RC1) provided insight into the number of modelling software systems available to produce VR/AR simulation. The first step as a novice was to find the software which had the easiest user interface (GUI) to learn and was available at low cost on the learner side. In addition to being able to utilise the GUI we also had to test and evaluate its technological enabler synergies with cognitive and social enablers. To assist in the identification of these synergies we recorded the learning activities and used

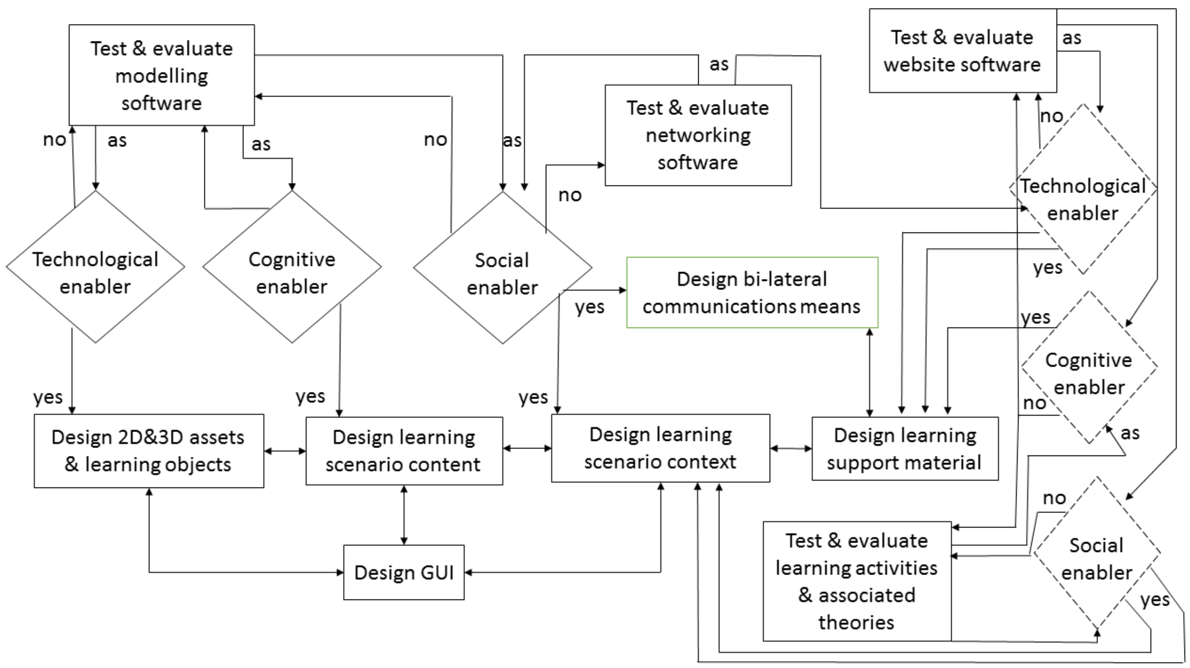
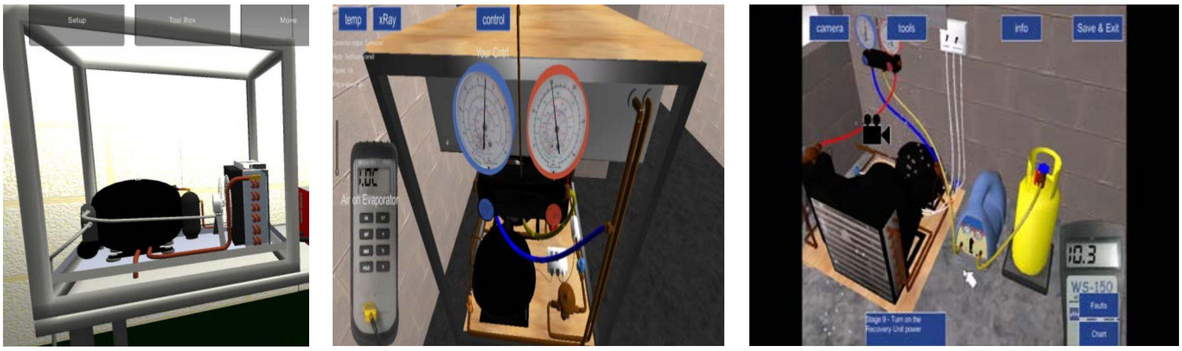


Figure 7.1: Workflow of development of WBS-LS

these recordings to identify social and cognitive interactions between learner to learner and educator to learner. As discussed a number of freeware open source software was tried and tested before finally settling on Blender™ and Unity™ as the preferred choice. Figure 7.1 illustrates that each time we got a 'no' result we reverted back to look for another or as was in our case a combination of two or more, before moving forward to the next stage.

'Test and evaluate modelling software' 'as' technological enabler meant checking that it could provide a means to replicate the learning assets and objects as identified from our digital recordings. The objects and assets in terms of file size had to be small enough to transport across the internet. A number of modelling software packages resulted in 'no' because of issues such as complicated GUI, file size of models to large or the system owners required payment to download software. Once we achieved a 'yes' as was the case with Blender™ and in addition Unity™, we proceeded to the next stage of the workflow which was to design and develop a learning environment. Designing the assets, learning objects, scenario content and context, the support material and communications means were all done by iteration. This meant we ended up with a number of build files. Figure 7.2 shows how the 3D models and 2D assets varied based on the cause and effect changes introduced each time we blended cognitive and social enablers with the technological software means.



a b c

Figure 7.2: Illustration of builds being improved by iteration

All software tested and evaluated as a technological enabler was also tested and evaluated for its ability to blend with cognitive and social enablers. This affectively meant that the software was able to support cognitive and social means by animation, voice chat, data storage and intuitive GUI. When one piece of software was limited we looked at compatibility and introduced the 'Mashup' process involving multiple software plugged in (networked) such as Uspeak™, Unity™, Blender™, Blacknight™, and Wordpress™.

7.2 Scientifically-based propositions

In line with main objectives of this promotion research, four propositions have been formulated that capture the main scientific contribution and results. Based on the content of the thesis, an additional four propositions have been derived, which project out from these and other achievements, and puts them into a social and personal context.

The completed research showed that stimulation game engine software and compatible 3D modelling software are a fundamental factor of handheld mobile devices used for everyday work and social activities by todays learner. This implies that today's learners' think digitally (systems learning) unlike the analogy (binary) thinkers of the generation before. The digital learners use digital systems to negotiate on their own way to gain a maximum reward (likewise the 'survival of the smartest'). The analogue learner uses an undeviating binary approach to realise their desired outcome (survival of the fittest). The implication of this finding was to identify resources that could adopt to the new digital way, increase cognitive agility and cultivate innovation by exploring alternative viewpoints and cross-disciplinary interpretations. Therefore the first proposition is as follows:

Proposition 1 ***A combination of augmented/virtual reality (AR/VR), gamification, and real life learning contexts is a true resource for the development of web-based dislocated construction engineering education environments***.

The results of our research showed that even with the everyday practice of using screen-based technology systems, introducing them as a solution for learning can be counterproductive. This also implied that there was a real challenge to introduce technology to a well-designed programme for learning. Re-orientation or change in thinking is required before selecting or deselecting systems for already established learning programmes. Converting an established learning programs system (without altering its essential content) from a continuously variable educator-centred application (designed by and delivered to analogue thinkers), to a digital multilevel learner centred approach (designed by and delivery to digital thinkers) requires a collaborative orderly approach. Thus our second proposition is as follows:

Proposition 2 ***Blending the latest technological enablers with emerging cognitive and social enablers creates opportunity for linking engagement and motivation to an effective and insightful learning process.***

The digital minds, that are owned by digitally literate learners, are a full set of learning processes that go beyond analogue linear learning. A digital mind embraces the full spectrum of technological advances. They adapt to the complexity of learning new knowledge in a modern technological world. This implies that game engine software development kits (SDK) (developed by digitally literate learners) associated with VR 3D game engine packages have enabled digital learners to produce detailed simulation of procedural activities with minimum computer programming knowledge. Open source freeware software platforms has resulted in the wider use of game engines for VR applications, particularly by non-programmers. This advancement in VR/AR technology has resulted in the practice of virtual construction in the pre planning stage of construction projects. This led us to formulating proposition number three.

Proposition 3 ***Relying on current technologies and enablers, practicing construction engineering educators and learners can now develop AR/VR-based interactive problem solving and learning environments***.

Literature recognises the increase in both the technological capacity and ownership of mobile phones. The implications of this is mobile phone manufacturers constantly improve and update their technology to maintain consumer market share. The resulting phenomena has resulted in learners who think that interacting with the digital screen of their smart phone establishes them as digital thinkers. However, the reality is that digital thinking is not about the considerations of technology, but more about a deep reflection upon the learners' goals and social contexts within which we are educating, learning, and conducting learning and other studies. This shows large differences. Adopting a learner-centered approach and incorporating technological enablers helps determine when technologies truly add value to learning experiences. Scientific proposition number 4 is:

Proposition 4 ***Human diversity must be a central consideration and should be accounted for at developing any form of online teaching and learning methodologies and tools.***

The literature presents evidence of the increased growth in collaborative online learning environments. The proliferation of these environments has resulted in that knowledge is shared and accessed across peer to peer-based multimedia streaming systems. However, typical peer to peer network architecture relies on a on a 'push message' approach, which reduces the reliability as there is and increase in traffic. The fluctuations in quality of service fail to meet the expectations of even the ordinary users and causes them to disconnect from the network. Therefore, we formulated scientific proposition number 5 so as:

Proposition 5 ***Real-time communication and live streaming optimisation are needed to enhance the fluidity of learner experience***

As documented in recent literature studies, the rate of advancement in the state of the art of speech recognition by digital devices has accelerated. The implication of such advancement in the direct reduction of the word errors rate and an increase in speeds of recognition. Smart hand-held devices are equipped nowadays with advanced voice recognition software, as well as quite sophisticatedspeech modelling resources and techniques. These not only significantly cpontribute to more accurate mathematical modelling and processiong of sounds and speeches, but also makes interaction more natural and robust in digital learning environments. Therefore our next proposition is that:

Proposition 6 ***If current smart devices are moving towards speech-based technologican interface solution, then developers of advanced learning systems should also move in this direction.***

Technology trends are bringing about a fundamental transformation in our society and consequently directly effecting traditional means of learning new knowledge. The two most distinguishing contributors to a year-on-year growth are the increase in nano-technology-grounded manufacturing of computer components. This in turn has increased the complexities, but also made it possible to integrate information technology in the form of a miniaturized chips (circuitry boards) that can be used in a ubiquitous way. Computation, communication, database access, and user interfacing has by now been combined into handheld (mobile) digital devices. On the other hand, the rapid evolution and rate of growth of such devices makes and prediction of future trends not only subjective, but also very uncertain, particularly for those complementary technologies (such as cognitive and semantic technologies, and cyber-physical computing), which are just beginning to appear on the consumer marketplace.

Proposition 7 ***Technological trends tend to evolve rapidly on a year-on-year basis with a fresh perspectives and novel developments, but adoption and use of these are not necessarily keeping pace with these.***

Despite the rapid spread and uptake of digital technologies, adoption and use vary at higher-level institutes among individual educators and learners. A division between those who use digital resources to teach/learn and those that don't raises concerns about the inclusiveness of the digital transformation. The environment that allows such a divide occur is usually created when there is a (i) lack of high-quality and affordable infrastructure, (ii) lack of trust in digital technologies and activities, and (iii) lack of professional development policy in the workplace to develop the skills needed to succeed in the digital economy.

Proposition 8 ***The two key inconsistencies that are currently slowing down the rate of technology introduction into education are the quality of internet connectivity and the level of difference in terms of digital literacy between learners and educators***

Based on their believed scientific and professional significance, Propositions 1 – 4 have been included in the separate sheet of propositions associated with this thesis.

7.3 Possible future research work

The natural progression for this research is to consider web-based stimulation learning application, exemplified as a non-linear, machine learning and an intelligence warehouse (IW) for transferring skills in construction engineering. The knowledge dissemination can be expanded into areas such as energy conservation and buildings maintenance. The Web-based learning application has the capacity to support self-managed acquisition of knowledge and skills for construction workers. The Intelligence Warehouse WEB which is a learning repository allows dislocated learners in industry to acquire skills and knowledge at their own pace.

Our multi enabler architecture can be applied to develop more advanced WEB learning platforms for further CE disciplines such as; buildings maintenance, conservation and energy retrofitting. The demand for remote on the go learning is increasing due to the mobile ubiquitous means of communication.

With the primary school generation of digital learners preparing to enter second level and finally third level education, there is an expectation that their need for a digital campus will be greater than that of the generations before them. The growing introduction of tablet devices into secon level and the increase in 'sandbox' design video games and 'CoderDojo' communities of practice, all point in the direction of an improved version of our WBS-LS architecture being implemented in the coming years.

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