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Developing an edugame simulation application for engineering
It works in practice, but will it work in theory?

Author: Garrett Keenaghan

College of Engineering and Built Environment, Dublin Institute of Technology

Abstract

This article describes the development of a web-based 3D simulation of an engineering workshop in refrigeration plant maintenance and the challenge of moving the application from a knowledge and skills acquisition model to a problem-solving edugame model across a range of possible scenarios within the restrictions of an academic programme's learning outcomes.

The 3D simulation workshop is described together with its real-world equivalent.

The limitations of the app. simulation in engaging students in complex problem-solving are described together with the search for learning design theories to inform further development of the app. as a multi-level, scenario-based edugame.

The article ends with an indication of the proposed collaborative process to further develop the app. by taking close cognisance of appropriate learning and gaming theories.

Keywords: edugames; cognitive absorption; scenario learning, perceptive immersive; flow theory.

1. Introduction

The research described in this article had its genesis on a real-life pedagogical problem on a refrigeration engineering course related to plant maintenance: how could web-based technologies be used to enhance learning from practical engineering workshops for students who are either off-campus or who do not learn effectively in workshop settings?

The initial solution was to develop 3D learning applications which virtually replicated the content and process of the workshops. While this was not a particularly novel solution, it did initially solve the learning problems for many students and increased their success rates with regard to knowledge and understanding. However, it did not necessarily enhance their problem-solving, higher level thinking skills when presented with unfamiliar scenario problems. The second pedagogical problem then was: could the 3D learning application be further developed to become a complex edugame with multiple, unpredictable scenarios which would both engage the students' cognitively and affectively, while enhancing their problem-solving skills within refrigeration engineering?

If this could be achieved, what theories of learning and of game design would support that development, or if indeed such combined theories already existed?

The current design stage, therefore, is a combination of a search for useful theory, development of a first-version prototype edugame that addresses the specific learning outcomes of the engineering programme, piloting the edugame app. with students, engineering colleagues and edugaming experts, and iterative development of the app. for multiple refrigeration engineering plant maintenance scenarios.

2. Development of the original 3D workshop simulation app.

The original 3D app. was developed by recording standard workshops for refrigeration engineering students on a module for plant maintenance.

Figure 1: Workshop-based training

Figure 2: Teacher-student interactions

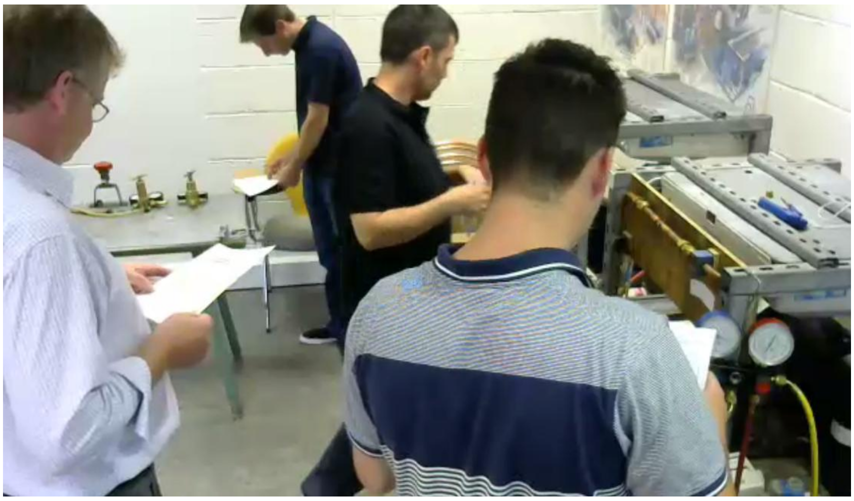


Figure 3: Noting student learning problerms

The development of the 3D learning app. was based both on recording the inputs of the workshop-based module *and* by observing the interactions between the teacher and students during the workshops (Figure 2). Areas of difficulty in understanding, skills application and problem-solving for students were noted.

A learning scenario was then designed based on those observations and notes which informed the sequencing in the design of the work-shop simulation app.

3. Designing the simulation app.

The simulation app. essentially replicated a typical workshop with a step-by-step teaching approach.

The following design points were significant:

- The app. had to be web-based and should be compatible with android phones.
- Photon software should be used since it would be a good fit with the gaming platforms young people are familiar with from xbox and playstation.
- Workshop equipment would be replicated in 3D as *virtually* close to the real-life context as possible.
- Voice was to be added with arrow indicators and *fully-operational* processes.
- Students could manipulate the equipment and replay elements were necessary.
- Students could test their knowledge and understanding of each element and stage, repeating as many times as possible.
- No tracking of student activity was included in the application so as to protect identity and to encourage self-styled learning.
- Students could use the app. to demonstrate to teaching staff that they had achieved the required learning of the module learning outcomes.

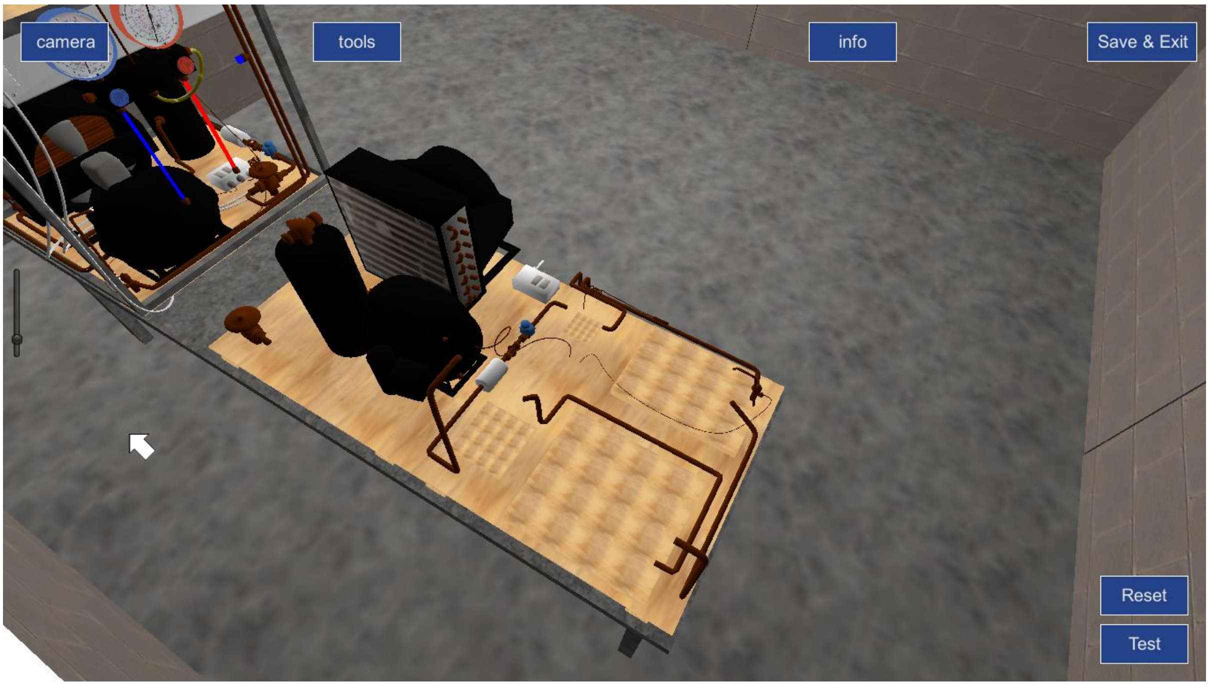


Fig 4. Replicated 3D object of engineering training equipment

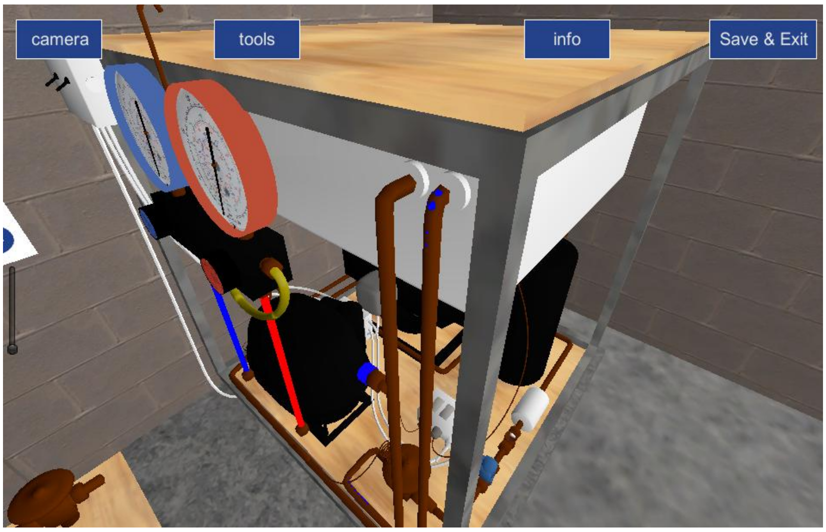


Fig 5: Virtual replication of refrigeration plant

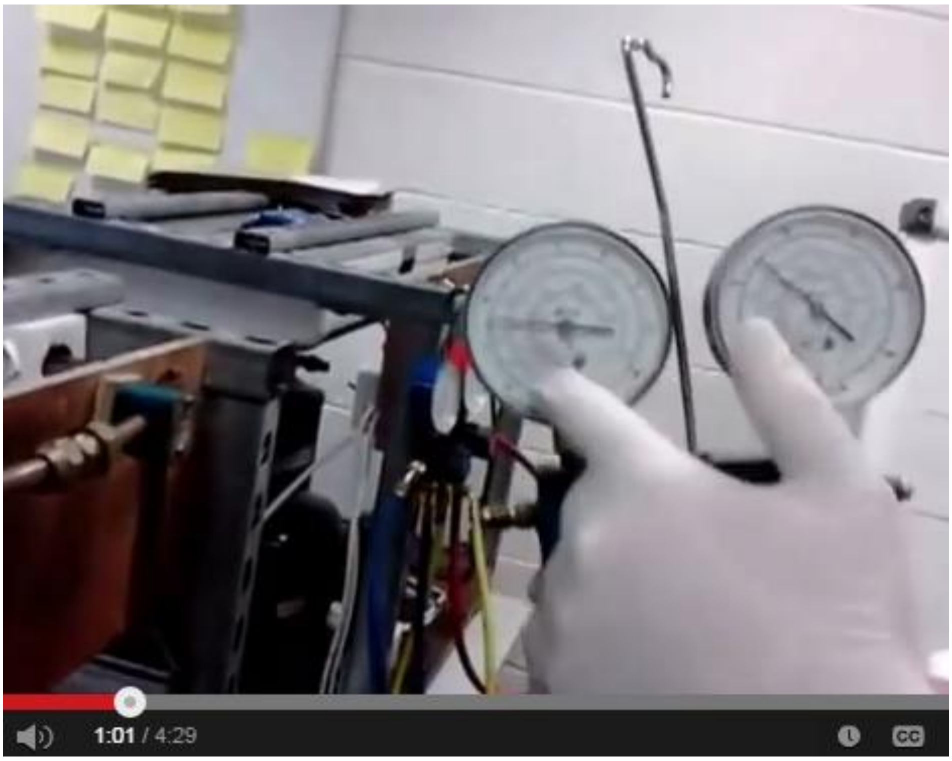
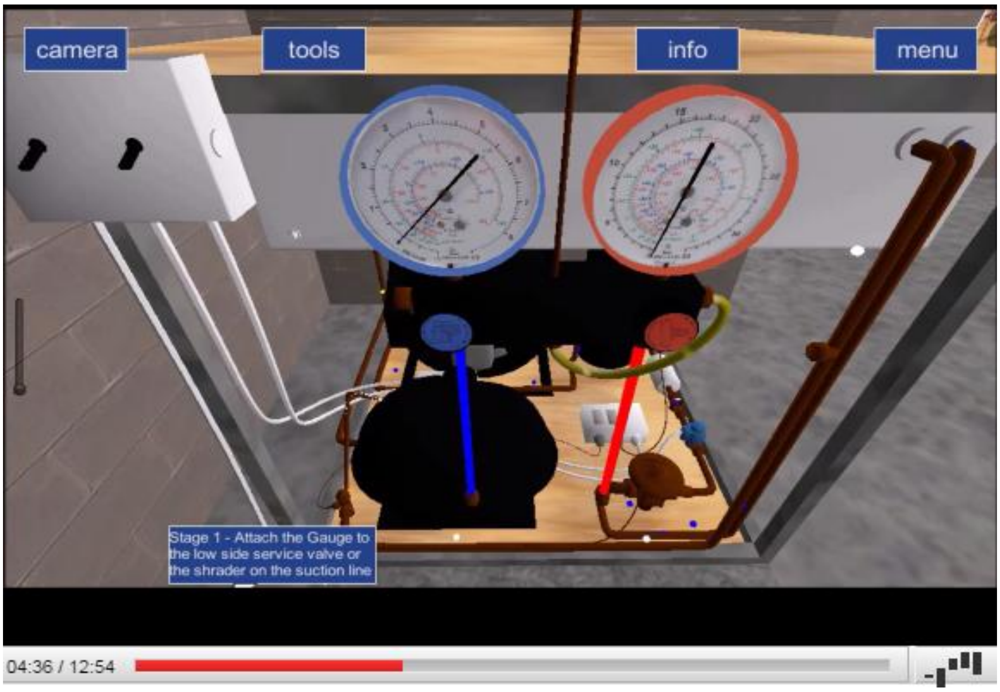


Figure 5: Work-shop equipment



Stage 1 - Attach the Gauge to the low side service valve or the shrader on the suction line

Figure 6: *Virtual* equipment

In the overall app. design it was necessary to keep in mind that all students taking refrigeration engineering within a built environment education context must achieve (i) a working knowledge and general understanding of refrigeration principles, (ii) ability to identify standard refrigeration system components, (iii) an understanding of the function, operation and construction of standard components and (iv) an understanding of how to maintain efficient operations of these systems. The app. worked well for this purpose.

The current workshop-based scenario for a student registered on such a module requires the student to attend all sessions in order to develop his/her practical portfolio and to complete his/her final assessment. A virtual workshop app. which recreates the real-life workshop environment gives off-campus students the opportunity to practice and learn procedural skills from a remote location using a virtual refrigeration plant.
The app. worked well in this context as well.

So, why was it necessary to understand the app. model theoretically?

4. It worked in practice: why are there problems of theory?

When it became clear that the app. had positive practical application it raised three important pedagogical questions as follows:

1. If the workshop environment is replicated virtually, and if students perform better with the app. than without it, how can we identify the principal psychological, cognitive, perceptive and affective dimensions that lead to this result?

2. If we succeed in identifying the dimensions in 1. above, how can they be integrated into the future design of the app. and provide for a more interactive and reactive learning experience that leads to higher order thinking and problem-solving skills?

3. Would there be merit in drawing on communications and gaming technologies used intuitively by young people when thinking about the app design, rather than thinking about pedagogical theory in the traditional sense?

These questions led to a search for a *good* theory, or at least *good sets* of theory.

What was known for certain is that our students are digitally-savvy and seem to learn effectively when multiple senses are engaged in the task. Digital learners frequently spend hours playing digital 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 (Lin *et al.*, 2006). As a result of the time and energy digital learners devote to playing games it seemed appropriate to explore the power these games have to motivate and engage users. Research literature that linked *engagement* and *motivation* to effective learning has led us to explore the use serious gaming as potential tools for enhancing the initial simulation app. (Kiili, 2005; VanEck, 2007; Prensky, 2001; Whitton, 2009). So, two theory sets were identified from the literature which seemed to be relevant. The two sets are outlined below.

5. First theory-set: engagement; motivation; flow theory; immersion; cognitive absorption; schema theory

The latest generation of communication technologies 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 (Tikhomirov, 2014). It is obvious that learners have more experience in the use of these technologies than is offered within traditional teaching systems (Schroth and Christ, 2007). The reason for this is that young people are essentially *digital learners* who interactively use new technologies outside of education. The new forms of knowledge dissemination must now become a major part of academic programme design. While the current generation of digital learners has embraced and is accepting of novel technologies and design principles, most teachers do not move at the same pace (ibid). There is growing research evidence demonstrating that, with the advancement of visualisation and virtual reality environments (VRE), technology-based cognitive stimulated learning enhances the learning experience (Lim *et al*., 2006).

Engagement

It has already been noted that digital learners frequently spend hours playing digital games, often returning to the same game over and over. They invest huge amounts of leisure time and energy into mastering complex game rules and strategies (ibid). The ability of technology to powerfully engage and intrinsically motivate users when delivered through digital game engine software is well documented (Rosas *et al*., 2003; Dickey, 2005; DeFreitas, 2007: Hoffman and Nadelson, 2010). The debate however has shifted and is now beginning to centre on the current generation gap between student and teacher. The recent advancement in technology, and how it is applied, highlights the main differences between yesterday's teacher and today's learner. If we start with the simple form of technology communications, *email* tends to be choice of the teacher while *text* and its abbreviated language, instant message and blogging tend to be the digital learners choice. Students want to create something like podcasts, blogs and wikis, and yet in the academic world, teachers who give students the freedom to create are in the minority rather than the majority. Today's digital learners are more likely to search online before ever resorting to a recommended text book. They approach learning differently and in contrast to traditional teaching methods. Motivating these students to attend lecturers on a regular basis is quite difficult as they are not passive learners willing to sit still and take instruction. It is widely accepted that today's students spends more time completing online, digital or other forms of technology-based tasks, than he/she will spend reading a book.

Ally (2008) discusses whether or not if any particular type of technology improves learning. He goes on to cite Clarke (1983) who contends 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. In support of this argument the work of Bonk and Reynolds (1997) argue that it is the instructional strategy, such as setting challenging activities, that forces learners to develop their cognitive abilities and improve the quality of learning rather than the technology itself. On the other hand Kozma (2001) brings forward the argument that the technology, when presented in 3D animated virtual reality, has an influence on the quality of learning. The literature does not specifically address the issue of learning experience when different technologies are used, but it does emphasise the importance of usability evaluation to enhance the effectiveness of its applications.

Motivation

Further research has shown that intrinsic motivation has numerous advantages over extrinsic motivation (Ormrod, 1999). Intrinsically motivated learners are more likely to pursue a task on their own initiative, persist in the face of failure, seek out opportunities to pursue the task and show creativity in performance (ibid). Intrinsic motivation is linked to cognitive engagement in learning because it keeps the learner's attention focused. New knowledge is learned in a meaningful way as deep learning rather than rote or surface learning, and knowledge gain is achieved at very high levels (ibid).

Flow theory

Closely linked to theories of motivation and engagement is *flow theory:* a term coined by Csikszentmihalyi to depict the state of mind experienced when one is completely absorbed by, and focused on, an activity to the point where all sense of time and external environment is lost (1990). Although initially thought to result only from play and leisure pursuits, Csikszentmihalyi showed that flow can be created through any activity, including work. The flow experience has various features. Firstly, people report that their concentration is solely and intensely focused on the activity at hand. Because they are so engrossed in this activity, they have few cognitive resources left, leading to a loss of self-consciousness. The user temporarily forgets their problems and can also lose awareness of self in the real world. They can experience a distorted sense of time. Regardless of whether the time seems to pass quickly or slowly, their individual perception bears little relationship to the reality of the clock. 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 (ibid). 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. 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 he/she is 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 user’s skills improve.

Modelling how students learn

There is a shift towards proactive and context-sensitive personal learning environments (PLEs) in the field of technology-enhanced learning (TEL) (Rahimi *et al*., 2014). Emphasises is on the students' role in controlling the educational process. This has in turn raised the need for modelling the student role in web-based learning processes, as well as the relationships to contents, media, and peers. Ambrose *et al* state the three critical components to defining learning are; (i) learning is a process and not a product, (ii) learning involves change in knowledge, beliefs, behaviours or attitudes and that this change occurs over time having a lasting effect, and (iii) learning is not something done to students but rather something students do for themselves (Ambrose *et al.,* 2010). Established evidence-based theories of learning are now recognised as central to the development of learning practice across all fields of learning activity. Berger states that '*we tend to conduct life based on many theories that are below the level of conscious thought and accepted without examination'* (Berger, 2000). The successful design of any educational system depends on the development of learning material which is fit for purpose with regard to the learning experience.

Immersion

Closely related to theories of engagement and flow is that of immersion. Conceptualisations of immersion vary. Brown and Cairns (2004) define immersion as the user's degree of involvement with a computer game, categorising it into three levels (ibid). At the lowest level, "engagement", the user is interested in the activity and is motivated to keep participating. The user progresses to the second level of immersion, "engrossment", when their emotions are directly affected by the activity and the device's controls become invisible to the user's senses. The third level of progression, "total immersion", will only occur when the player feels cut off from reality to the extent that the activity is all that matters (demonstrating parallels with the flow experience). On the other hand Lombard and Ditton (1997) distinguish between immersion in a 3D virtual environment as either (i) psychological immersion or (ii) perceptual immersion (ibid). Psychological immersion refers to the user's mental absorption in the virtual environment activities. The user is drawn into the world through their imagination. Perceptual immersion refers to the extent to which an individual is immersed in an activity through the senses. It is posited that when both levels of immersion are attained, 'situated immersion' (Alexander *et al*., 1997), 'total immersion' (Brown and Cairns, 2004) or 'presence' (Bartle, 2007) can occur. This is when the individual engrossed in the activity has the subjective experience of actually existing within a virtual time and space when he/she is physically situated in real time and space. The result of a person's experience can determine improved performance and measure the potential for future success.

Cognitive absorption and schema theory

Cognitive absorption of knowledge and skills can be influenced in a web-based stimulation system (WBSS), by introducing perceptive and psychological immersive techniques as a fundamental element of the design framework. The WBSS tries to replicate a real-world workshop by using the most current software and hardware. Immersive technologies provide the additional human senses beyond visual (sound, touch, smell, impact). Immersive hardware technologies are expensive and not always accessible to the student population. Therefore it is important to introduce a WBSS which uses both perceptual and psychological immersive techniques to provide an enhanced interactive and reactive learning experience. Building on what is already known from schema theory employed by cognitive psychologists (Bruner, 1986) and artificial intelligence (AI) researchers, it is possible to chart how the information processing process can shape perception and action (Bolter and Richard, 1999). Schema theory is a conceptual foundation for which to build a learning app. or edugame. That way one will have a cognitive framework to determine (i) what target learners know about the world, (ii) the objects which are familiar to them in their world, (iii) the tasks they perform and (iv) what each individual thinks he/she senses (Schank, 1990).

Theory set 2: cognitive enablers; technological enablers; social enablers

The second set of theories identified in the literature include: (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 other two enablers in the form of cognitive knowledge and skills absorption. The concept of an interactive app. is based on blending of technological, cognitive and social enablers. Figure 7 illustrates the close integration of the enablers which at times can be one and the same. The integration of technological, cognitive and social enablers is a natural phenomenon. The level and format will 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.

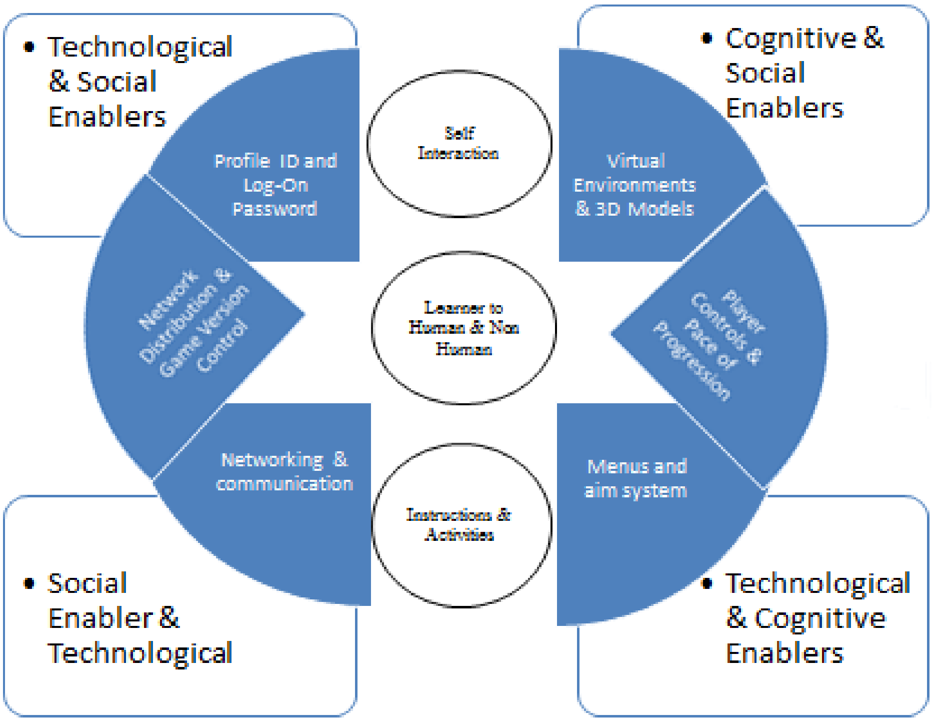


Figure 7: Integration of enablers

There is no evidence of a theory in the current literature that explains how to blend these enablers. As a result there is no evidence of implementation which we can learn from. The technological and social enablers are tangible and obvious to identify and measure in comparison to the cognitive which is considered to be an abstract enabler. In order to identify how perceptual and psychological immersion can be evaluated, learning scenarios must be established and assessed.

Next steps?

For the purpose of further developing the app. it is intended to design a learning scenario and divide it up into three sections (i) image and text scenario, (ii) video and (iii) interactive element. A group of expert peers from computer science, engineering and egaming pedagogics will act as a critical focus group, together with students, to evaluate if the theoretical dimensions identified above are appropriate and valid, or is a new set of theories is required.

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