A Serious Game for the Tuition of First-Order Logic

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Chapter 1

Literature Review and Technology Survey

1.1 Games

Before defining Serious Games, it is imperative to first define 'games'. Kapp (2012) presents the following definition:

"A game is a system in which players engage in an abstract challenge, defined by rules, interactivity, and feedback, that results in a quantifiable outcome often eliciting an emotional reaction."

1.2 Serious Games

The definition of a Serious Game is one of contention. Serious games, as described by Abt (1987), have an *"explicit and carefully thought-out educational purpose and are not intended to be played primarily for amusement"*. However some authors, such as Jantke and Gaudl (2011), note that game developers rarely state their intentions which can make it difficult to judge whether they have been truly reflected in the final game whilst others, such as Sawyer (2009), disregard Serious Games as merely a marketing term. Abt's definition has been chosen for the purposes of this project.

It is important to distinguish Serious Games from similar terms which appear in the literature, notably: gamification, simulation and game-based learning.

Gamification, as defined by Kapp (2012), is *"a careful and considered application of game-thinking to solving problems and encouraging learning using all the elements of games that are appropriate."* It employs game elements in a non-gaming context to enhance engagement. This contrasts with Serious Games which are custom-built games in their own right with a specific learning objective. However, they can be considered a form of gamification when incorporating game elements specific to enhancing engagement.

Simulations allow users to learn practical skills from an artificial environment that was built to mimic a real-world process (Morgan, 1984). This often involves complex hardware. By contrast, Serious Games only require a computer or mobile device to operate it. They do not attempt to imitate any real-world process. Instead, they consist of game components tailored to the tuition of concepts in a subject.

Game-based learning is the term that resembles Serious Games the most. Both apply game-based techniques to enhance the player's knowledge of a given problem-domain. However, Serious Games exist in the digital realm, whereas mediums that embrace game-based learning include board games and card games (Tsekleves, Cosmas and Aggoun, 2014).

Serious games have applications across a number of domains including healthcare, defence, culture, religion, corporate training, and the domain of this project: education (Djaouti et al., 2011).

1.3 Serious Games in Education

Motivation

Games are fun: they can motivate people to learn regardless of their initial interest in the subject matter (Reigeluth and Squire, 1998). A distinction can be made between extrinsic and intrinsic motivation. The ratio of extrinsic to intrinsic motivation in players can vary from person-to-person. However, the incentive of trying to win a game, which is an extrinsic motivation for learning, can often draw players into the learning activity, which can then stimulate an intrinsic interest in the subject matter (Lepper and Henderlong, 2000).

Engagement

Games are engaging. Active participation in a game requires a deep level of concentration from the player in order to apply knowledge, make decisions, devise strategies and predict outcomes effectively (Lieberman, 2006). People who are resistant to learning using traditional methods of learning, are happy to engage in what has been dubbed as "productive play" i.e. the learning and accomplishment that can occur when playful activities lead to problem-solving (Rieber, 1996).

Interactivity

Games are interactive: they can adapt to the actions of the player. Choi and Hannafin (1995) claim that Serious Games provide the kind of support tutors give to students. Interactivity in a Serious Game can involve feedback on the player's actions or hints to nudge the player in the right direction (Betz, 1995). Feedback is a key component of both games and education: it allows players or learners to learn from their actions or reassess their understanding of a topic. Care has to be taken to make sure that feedback is clear and not overwhelming. Furthermore, the components of interactive games that make them compelling are the same components that enhance engagement and motivate learning (Lieberman, 2006).

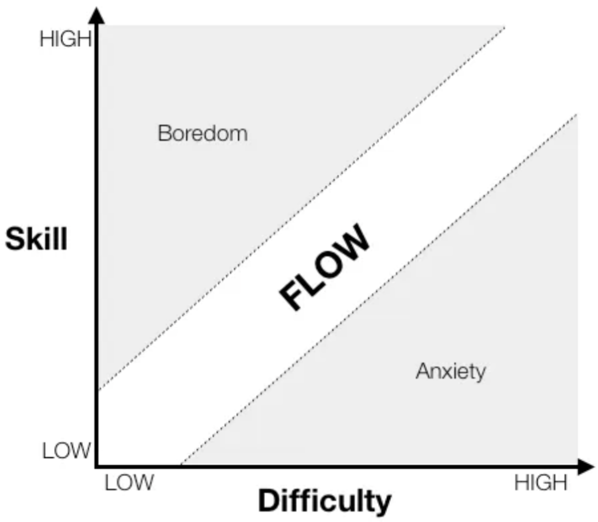
Level Progression

Games usually consist of level progression. This is defined as a series of levels that advance in difficulty. It can be used as a means of organising the delivery of concepts. People do not tend to cope well when they have to process large amounts of information (Sharp, Rogers and Preece, 2007). One suggestion could be to split large information into smaller chunks that are delivered on separate levels. Then, relevant concepts could be introduced before they are to be applied. This makes sure that players can complete any given level, based on the concepts taught so far by the game. For that reason, levels should increase in difficulty in a way that is perceived to be manageable by the player.

Flow

Games that are particularly engaging, enable a state of flow (Weisler and McCall, 1976). Lieberman (2006) describes flow as a state of *"well-being and increased cognitive efficiency that occurs during an absorbing task. People experience flow when they are challenged enough to do their best, yet not challenged beyond their abilities"*. There are two factors that have to be scaled appropriately in order to establish a flow state: difficulty and skill (Csikszentmihalyi, 1990). Flow is the balance between these two states (see Figure 1.1). If a task is too easy to complete and requires some skill, it becomes too boring. Conversely, a difficult task that does not require a lot of skill has the potential to induce anxiety.

Figure 1.1: Flow as a Balance between Difficulty and Skill. Adapted from Csikszentmihalyi (1990).



To achieve a balance, Csikszentmihalyi (1990) outlined four elements of tasks that increase the likelihood of inducing a flow state. These are tasks that:

1. Have concrete goals with manageable rules.
2. Include goals that fit player capabilities.
3. Have clear and timely feedback.
4. Eliminate distractions.

Players can disengage when they are unclear on what their goals are and how to accomplish them. This could increase the likelihood of them giving up on playing the game, and thereby the subject matter.

Players are not able to complete goals if they are incapable of achieving them. This means that someone playing a Serious Game must be able to complete a task given adequate instruction and information. People are able to understand and apply relevant information to a task when there is congruence between the task and the information presented to them (Baron, 2012). A lack of congruence can lead to breakdowns in information processing which can frustrate players and break their flow.

Clear and timely feedback is critical in feeding further engagement. This encourages players to keep learning a subject in a Serious Game. Most notably, feedback that occurs directly after (200 to 400 milliseconds) or midway through the completion of an action leads to the formation of the strongest associations between action and outcome (Baron, 2012). This strengthens the argument for a smooth interface that delivers feedback on the player's action almost instantaneously.

Distractions can interrupt flow. Visual and informational clutter can make it harder for a player to identify and apply relevant information. A Serious Game can minimise distractions by enforcing a minimalist design and a custom-built environment that is geared towards the tuition of concepts in a given subject.

Goals

Goals can be a source of motivation. The goal of a Serious Game is to achieve the learning outcomes set by the game developer whereas the goal of a singular level is to either learn new concepts or apply the concepts taught thus far. Trying to achieve a goal assists in immersion which can help induce a flow state. Learning that occurs in the process of attempting to reach a goal can increase a player's motivation (Cordova and Lepper, 1996), and thereby likelihood to achieve the learning outcomes set by the game developer. The act of achieving goals is rewarding and reinforces actions that encourage players to pursue the completion of subsequent goals which can further increase their knowledge of concepts in a given subject.

1.4 Serious Games in Computer Science Education

The following examples of Serious Games are catered for the tuition of topics from a typical Computer Science curriculum. As such, each example draws upon a number of characteristics illustrated in Section 1.3.

Scratch

Scratch is "a visual programming environment that allows users to learn computer programming" (Maloney et al., 2010). The platform aims to teach programming in a way that allows users to "tinker" with code and see the outcome without overloading information onto the user. It employs a user-friendly interface, that likens code segments to building blocks or puzzle pieces, as well as simple pointing device gestures such as, "drag and drop" commands on desktop and touchscreen gestures on other devices. These commands are used to assemble the code segments to a working program.

Scratch also promotes an active and growing community (Resnick et al., 2009) which further increases engagement. This hand-on approach to programming is an example of experiential learning. The platform is also highly interactive, providing feedback to the user on the output of their code instantaneously.

One limitation to Scratch is that it delivers a false impression of programming. Programming is not a case of memorising syntax or assembling a bunch of ready-made code; it is about developing a mindset of resilience and algorithmic thinking. In particular, the ability to look at a problem, break it down into smaller steps, code a solution and modify it accordingly. A counter-argument to this could be that Scratch was not developed as the only tool to learn programming, but merely as an introduction to programming.

Whilst the platform was developed for users between the ages of 8-16 (Maloney et al., 2010), one study found that Scratch was both enjoyable and effective at teaching programming to undergraduate engineering students (Özoran, Cagiltay and Topalli, 2012). Thus, this study asserts the notion that Serious Games are an effective learning tool at university level within the Computer Science curriculum.

Minecraft

Minecraft is a sandbox game; a game in which users are expected to explore and change a virtual world at will (*What is a Sandbox (in Gaming)*, 2017). Similar to Scratch, Minecraft makes use of building blocks. Users gather resources, made from these building blocks, to make their own objects.

Educators have incorporated this feature into their own teaching plans to deliver a hands-on-approach to learning. Most recently, Microsoft has extended access to Minecraft: Education Edition (MC:EE) to support remote learning during the Covid-19 pandemic, for those with a valid Office 365 Education account (Minecraft, 2020). Features like *classroom multiplayer* allows players to collaborate on projects in their Minecraft worlds and chat to one another which helps bolster a sense of community and boosts engagement. This allows students to build their communication skills as well as their ability to problem-solve. Additionally, it applies the sociocultural theory of development, which suggests that learning takes place when students solve problems beyond their current developmental level with the support of their instructor or their peers (Vygotsky, 1978).

A limitation of Minecraft, pointed out by a review into the Education Edition, observed that the game was designed for players with a basic literacy in video games which may lead non-gaming learners to feel alienated by the lack of clear goals and structure in the game (Kuhn, 2018). This can also interrupt a player's flow.

A counter-argument could be that the level of interactivity offered by a sandbox game could allow students to learn concepts implicitly rather than explicitly. This allows students to gain a better understanding of a concept because they discovered it themselves which may increase their likelihood to recall this information and apply it in the future. It also contrasts with more traditional levels of instruction where information is "dumped" on a learner and requires a certain level of attention from the learner in order to absorb the material. Instead, Minecraft relies on the player's curiosity to navigate a virtual world and experiment with the elements presented to them.

Make It True

Make It True is a mobile application for Android devices. It was created to teach concepts pertaining digital circuits including Boolean logic, logical connectives, their corresponding truth tables and their symbolic representation in digital circuits. Each level has a logic circuit for the player to complete. Each circuit is solved by setting the voltages of the input wires at the bottom of each circuit to either 1 or 0. The difficulty of the circuits increases as the player progresses.

Trial-and-error is often resorted to in higher levels due to pressure from an in-level timer. Whilst this was initially perceived as a limitation, Jones et al. (2010) stated that "making errors when learning may be more advantageous when training has to be transferred to a novel situation". Applied to a university context, this could mean that players could use trial-and-error in a Serious Game and transfer their learnings to an exam on questions concerning those topics.

The suitability of a mobile application as a learning tool in the classroom is still up for debate. Mobile devices are still perceived by many as a means of distraction (Junco, 2012). Since many students own a mobile phone and have it on their person, they could be more likely to play a Serious Game if it was already installed on their mobile phone. However, neither classroom lessons nor lectures allow adequate time for students to play a Serious Game and the possibility of getting distracted by other features on their phone still remain.

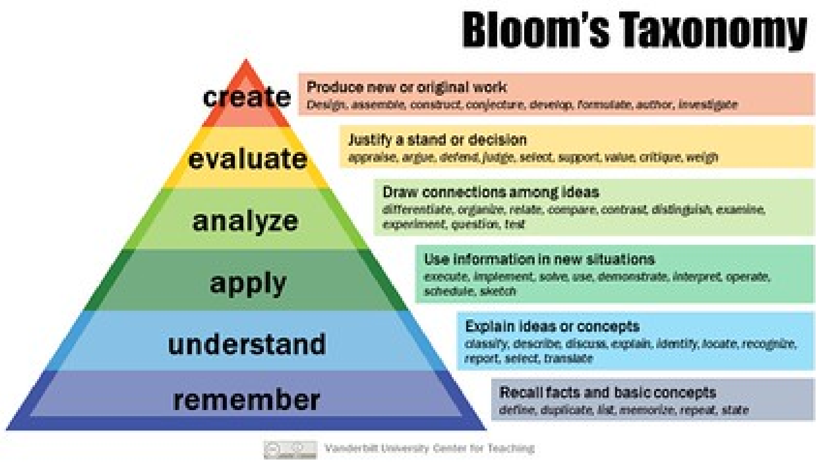
Thus, an analysis of Make It True supports the creation of a web application for maximum accessibility, to allow players to access the game from any device whenever they need.

1.5 Teaching First-Order Logic

Current Methods

Concepts in first-order logic are taught from GCSE through to degree level. Therefore, it is necessary to examine the current methods for teaching first-order logic from GCSE. These span from classroom activities and textbook material derived from exam-board specifications at GCSE and A-level to lectures, problem classes, seminars and further reading at degree level. Barring classroom activities and problem classes, much of the learning that takes place is passive.

Figure 1.2: Revised Bloom's Taxonomy. Adapted from Anderson and Krathwohl (2001)



Passive learning reflects traditional methods of learning in which students learn directly from the teaching material. This is in stark contrast with *active learning* which is commonly defined as *"activities that students do to construct knowledge and understanding"*. Whilst these activities can vary, they all require higher-order thinking, i.e. levels of learning higher than recalling and understanding material, as illustrated in Bloom's Taxonomy (see Figure 1.2) (Anderson and Krathwohl, 2001).

Passive learning is often coupled with *explicit instruction.* Activities such as reading directly from a textbook or listening to a lecture requires a certain level of attention from the learner. A lack of attention can impair memory for learning material since the information was not captured properly in the first place (Farley, Risko and Kingstone, 2013).

Alternative methods, such as Serious Games, seek to overcome the limitations that are related to traditional methods of learning.

A Serious Game to Teach First-Order Logic

By nature, Serious Games are a vehicle for players to practise higher-order thinking (see Figure 1.2) in a specific knowledge domain. *Experiential Learning*, or "learning by doing", allows players to discover concepts for themselves through a hands-on approach to learning (Dewey, 1938). This could serve as a better tool to facilitate understanding of a problem-domain over explicit instruction. A better understanding of a subject matter facilitates better recall of concepts in the subject matter (Ndoye, 2003).

In order to adopt the benefits associated with Serious Games, the game itself must first be fun to play. First-Order Logic involves some mathematical notation that requires learners to overcome a steep learning curve. The interactive nature of a Serious Game can provide feedback on a player's actions that can help them to build a solid foundation which they can advance their knowledge of the subject.

However, it is important not to neglect the educational content in a Serious Game either. Many Serious Games fall into the trap of not basing their content on well-established theory (Tsekleves, Cosmas and Aggoun, 2014). This indicates the importance of first scoping the traditional methods in which the subject matter is taught.

The core goal of teaching is to bridge the gap between what students already know and what teachers need to convey. The more experienced a teacher is, the greater the likelihood of them forgetting what it was like for them to approach the subject in the first place. This might make it harder for them to gauge what their students already know and what concepts they are likely to struggle to learn. One way to gauge this could be to observe playthroughs of the application to assess how someone unfamiliar with the game plays it and see where they struggle. From this, one can adjust the delivery of taught concepts and level of instruction required to complete tasks in the game.

Testing the application will not fully illustrate the effectiveness of the application, but it does have the potential to start a line of enquiry into the effectiveness of a Serious Game at teaching concepts in First-Order Logic. Testing needed to gauge the benefits of Serious Games is subjective in nature.

Due to the limited scope of this project, it is important to note that the final product will not attempt to teach every concept of first-order logic, but serve as an introduction to the subject and an attempt at teaching a few fundamental concepts well. The application will serve as a supplement to a curriculum rather than a complete tool to learn First-Order Logic.

1.6 Summary

This chapter has examined literature in Education and Psychology, in addition to literature specific to Serious Games, to analyse the use of Serious Games as a learning tool. To make a Serious Games, it was important to first define it and differentiate it from similar concepts such as gamification, simulations and game-based learning. It has analysed the benefits and limitations of three Serious Games geared to topics in Computer Science to inform best practices for the development of this project. The chapter finally concluded with a comparison between Serious Games and conventional teaching methods.

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