Using Digital Game-Based Learning to Engage Science Students:

The Case of *Minecraft*

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Abstract

This paper discusses the potential benefits of Digital Game-Based Learning for promoting student engagement, problem-solving, collaboration and learning of science concepts. It analyses the theoretical underpinnings that support the use of digital games in education, and examines the specific characteristics of digital games which embody positive learning principles that can be used for educational purposes. The digital game *Minecraft* is used as a case to demonstrate that there are many advantages to using digital games to teach science concepts in school and university contexts.

*Keywords*: Digital Game-Based Learning, Minecraft, games in education, student engagement
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**Introduction**

Many science teachers have faced demotivated students unwilling (or unable) to learn. Student engagement has been shown to be one of the essential requirements for learning and is highly correlated with achievement in school (Finn & Zimmer, 2012; Potter, 2014). By engaging students it is possible to promote their educational performance and their overall academic success (Finn & Zimmer, 2012). Instructional approaches that are designed to encourage student participation should take into account that modern-day students have been raised in a digital, media-saturated world and require similar learning environments to hold their attention (Kinash, Wood, & Knight, 2013; Prensky, 2001b). The use of digital games in education has increased significantly over the past few decades and shows promise of engaging digital native learners (Edery & Mollick, 2009; Prensky, 2001a; Schifter & Cipollone, 2013; Warren, 2015b). I will discuss how Digital Game-Based Learning (DGBL) has the potential to not only motivate and engage students in learning science, but can also help promote problem-solving, collaboration and the learning of specific science concepts such as physics and chemistry. Specifically, I will discuss the benefits of one such digital game, *Minecraft* (https://minecraft.net/), and argue for its implementation in school learning.

**Digital Games and Digital Game-Based Learning**

Before we can discuss the benefits of digital games in education, it is important to define what exactly is meant by the term ‘digital game’, to understand the history of DGBL, and the educational theories and principles that support it.
History of Digital Game-Based Learning

Computer-based games are not new to education. Seymour Papert’s Logo™ is a programming language designed over 45 years ago that was used by teachers to teach a variety of subjects, including mathematics, language, music and science (Papert, 1980). With the advent of new technologies such as tablets and smartphones, the term ‘computer games’ eventually changed to the more generic ‘digital games’. Digital games are interactive programs played on digital devices (such as computers, consoles or smartphones) by one or more players, for the purpose of recreation or instruction. They can be thought of as adaptations of ‘traditional’ game systems, with rules, player representation, and environment managed through electronic means (University of Washington, 2005).

The term Digital Game-Based Learning was made popular by Prensky (2001a, 2001b), one of the world’s leading experts on the connection between education and technology. Prensky argued that young children are ‘digital natives’ that have been exposed to digital devices from a very young age, and have developed skills that need to be acknowledged in schools and universities, notably by engaging and teaching them through digital games (Prensky, 2001a, 2001b). DGBL is any activity that is designed to promote learning and allows learners to practice their skills in a virtual environment (Erhel & Jamet, 2013).

For the last decade the concept of DGBL has caught the attention of many educators, as can be seen by the number of games-based special interest groups at national conferences and international conferences specifically about games in education (Schifter & Cipollone, 2013). This is not surprising, as playing digital games has become a popular recreational activity in recent years. The Entertainment Software Association (ESA, 2014) reported that 59% of all Americans play digital games on computers or game consoles; 61% of players are between 18
and 35 years old; and on average players have more than 14 years of experience in playing digital games. This data suggests that many learners now have grown up playing digital games (Edery & Mollick, 2009). Over the past 20 years, educators have been implementing digital games with K-12 learners to varying degrees (Warren, 2015b). This has led to many researchers looking into the learning principles behind DGBL, which I shall describe next.

**Educational Principles of Digital Game-Based Learning**

Many digital games are long, complex and difficult to play, particularly for novice gamers (Gee, 2004). However, this does not prevent thousands of people from spending countless hours in learning the mechanics and rules of the game so that they can master it. It seems that game designers have solved an educational dilemma that plagues many schools and universities: how to get young people to learn and master something that is long and challenging, while having fun doing it (Gee, 2003).

Gee (2004) found that there are many learning principles that digital games use which are supported by educational and cognitive science research. It is important to note here that not all digital games are good for learning, and not all games exhibit these positive learning principles that can be used for teaching in schools. Table 1, adapted from Gee (2004), shows a list of the good principles of learning that can be built into digital games. This table can be used as a checklist: the stronger any game is on more of the features on the list, the better its score for learning. Effectively, these traits can be used to distinguish between “good” digital games which can be used for effective learning, and games which do not demonstrate these positive learning principles.
<table>
<thead>
<tr>
<th>Principle</th>
<th>Description</th>
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<tbody>
<tr>
<td>Co-Design</td>
<td>Good learning requires that learners feel like active agents (producers) not just passive recipients (consumers).</td>
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<tr>
<td>Customize</td>
<td>Different styles of learning work better for different people. People cannot be agents of their own learning if they cannot make decisions about how their learning will work.</td>
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<td>Identity</td>
<td>Deep learning requires an extended commitment and such a commitment is powerfully recruited when people take on a new identity they value and in which they become heavily invested.</td>
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<td>Manipulation</td>
<td>Human perception and action are deeply inter-connected. Fine-grained action at a distance causes humans to feel as if their bodies and minds have stretched into a new space. Humans feel expanded and empowered when then can manipulate powerful tools in intricate ways that extend their area of effectiveness.</td>
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<td>Well-Order Problems</td>
<td>The problems learners face early on are crucial and should be well-designed to lead them to solutions that work well, not just on these problems, but as aspects of the solutions to later, harder problems.</td>
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<td>Pleasantly Frustrating</td>
<td>Learning works best when new challenges are pleasantly frustrating in the sense of being felt by learners to be at the outer edge of, but within, their “regime of competence”. Furthermore, learners get evidence that their effort is paying off in the sense that they can see, even when they fail, how and if they are making progress.</td>
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<td>Cycles of Expertise</td>
<td>Expertise is formed in any area by repeated cycles of learners practicing skills until they are nearly automatic, then having those skills fail in ways that cause the learners to have to think again and learn anew.</td>
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<tr>
<td>Information “On Demand” and “Just in Time”</td>
<td>Human beings are quite poor at using verbal information (i.e., words) when given lots of it out of context and before that can see how it applies in actual situations. They use verbal information best when it is given “just in time” (when they can put it to use) and “on demand” (when they feel they need it).</td>
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<td>Fish Tanks</td>
<td>If we create simplified systems, stressing a few key variables and their interactions, learners who would otherwise be overwhelmed by a complex system get to see some basic relationships at work and take the first steps towards their eventual mastery of the real system.</td>
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<tr>
<td>Sandboxes</td>
<td>Sandboxes in the real world are safe havens for children that still look and feel like the real world. If learners are put into a situation that feels like the real thing, but with risks and dangers greatly mitigated, they can learn well and still feel a sense of authenticity and accomplishment.</td>
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<tr>
<td>Skills as Strategies</td>
<td>People learn and practice skills best when they see a set of related skills as a strategy to accomplish goals they want to accomplish.</td>
</tr>
<tr>
<td>System Thinking</td>
<td>People learn skills, strategies, and ideas best when they see how they fit into an overall larger system to which they give meaning.</td>
</tr>
<tr>
<td>Meaning as Action Image</td>
<td>Humans do not usually think through general definitions and logical principles. Rather, they think through experiences they have had. Furthermore, for humans, words and concepts have their deepest meanings when they are clearly tied to action in the world.</td>
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</table>
Good games also embody well-established theories of learning. Firstly, many games are situated within meaningful contexts – what you learn is directly related to the environment in which you learn and demonstrate it (Van Eck, 2006). This theory is referred to as Situated Cognition and has been demonstrated to be an effective learning principle (Lave & Wenger, 1991; Van Eck, 2006). Secondly, good digital games also embody Piaget’s process of cognitive disequilibrium and accommodation, in that they continuously challenge the player’s assumptions about the game, without exceeding the capacity of the player to succeed (Van Eck, 2006). This means that interacting with a good game requires a constant cycle of hypothesis formulation, testing, and revision, and keeps the players engaged. Thirdly, the constructionist learning theory can also be seen within good digital games. Constructionism is the idea that learning is most effective for learners when they are able to construct meaningful products that are tangible and shareable, and is inspired by Piaget’s constructivist learning theory (Papert & Harel, 1991). Finally, good digital games also exhibit aspects of Vygotsky’s concept of the Zone of Proximal Development (Vygotsky & Cole, 1978), in that they provide challenges to the players that are just beyond their current level, and provide scaffolding to help players reach new levels of mastery within the game.

Thus it can be seen that there are many educational theories and principles that support the implementation of DGBL. Next, I will discuss some of the benefits of implementing these digital games into schools and universities.

**Benefits of Digital Games in Education**

Over the past 50 years, there have been many studies which have looked at the benefits of gaming in education, and many of them have shown positive effects of DGBL across multiple disciplines and learners (Van Eck, 2006). Game players learn to take in information from many
sources, make quick decisions, to create strategies for overcoming obstacles, to understand complex systems through experimentation, and to deduce a game's rules from playing rather than by being told (Prensky, 2001a). Many of the games used in DGBL (e.g., Quest Atlantis, Citizen Science, River City and Environmental Detectives) are either designed to support specific subject learning, or to improve learner problem-solving, collaboration and engagement (Schifter & Cipollone, 2013; Warren, 2015b).

**Student Engagement:** Motivation is the most important factor that drives learning (Gee, 2003). DGBL has been recognized for its capability to motivate and engage learners cognitively, emotionally, and socially (Huang & Johnson, 2008; Huang, 2011, 2015; Prensky, 2001b). According to Huang (2015), digital games provide both intrinsic motivation (in the form of providing challenges, arousing curiosity, and affording fantasy environments) and extrinsic motivation (in the form of scoring systems, guiding activities with rules, and opportunities to gain advanced competence status). These different motivational aspects can provide incentives for students to invest time and effort into playing the game, and can be a useful tool in promoting learning within the classroom (Huang, 2015; Rosas et al., 2003). Consequently, games have the potential to positively impact student time-on-task and attitude toward learning subject matter, and thus improve learner achievement (Warren, 2015a, 2015b).

**Problem Solving:** Digital games can offer immersive experiences in which players demonstrate higher-order thinking skills such as strategic thinking, interpretative analysis, problem solving, plan formulation and execution, and adaptation to rapid change (Federation of American Scientists, 2005; Huang, 2015; Squire, 2008). Game-playing processes can provide meaningful problem-solving experiences as they demand constant efforts from players to develop and then try out different solutions to accomplish tasks (Huang, 2015). By providing constant feedback to
players, a game system can reinforce the effects on problem solving and learning by doing (Huang, 2015).

Collaboration: Many studies have found that digital games can promote collaboration and cooperation amongst students (Huang, 2015; Kimmons, 2015; Rich, 2015; Squire, 2008). Multiplayer games require that team members communicate with others to coordinate their actions and decisions, and provide opportunities for players to learn from each other’s successes and mistakes (Huang, 2015). This is particularly true for games in higher education, in which collaboration was found to provide the most consistent increased learner outcomes over most other instructional methods (Rich, 2015). Additionally, when players participate in massive multiplayer games they often collaborate in teams, each using a different, but overlapping, set of skills, and share knowledge, skills, and values with others both inside the game and on various Internet sites (Gee, 2003). The 2012 New Media Horizon report suggests that games such as Minecraft and World of Warcraft have been integrated into college curricula because they effectively bring learners together in ways that encourage collaboration and problem solving and that foster skills such as teamwork, leadership, and discovery (Johnson, Adams, & Cummins, 2012; Rich, 2015).

Science and Gaming: An area in which DGBL has most often been employed is science education (Warren, 2015a). In the United States, the National Science Foundation and the National Institutes for Health are responsible for much of the funding for science-based games (Warren, 2015a, 2015b), which implies that DGBL is being seriously considered as an educational learning strategy. Many science games have been designed for both elementary and secondary school learners (e.g. MEGA, Citizen Science, and Environmental Detectives), and these games have been shown to improve student learning of complex concepts ranging from
computer science to environmental consequences that stem from their decision making (Prensky, 2001a; Warren, 2015a, 2015b). In a science classroom, learning works best if students think, act, and value like scientists (Gee, 2003). Thus digital games can show us how to get people to invest in new identities or roles, which can promote deep learning in science classrooms (Gee, 2003). One digital game which has been implemented in science classrooms across the world is *Minecraft*.

**Minecraft**

*Minecraft* is described as a ‘sandbox-building’ game, because of its open world structure and freedom of play. The game world consists of uniform meter-square cubes of different materials (such as dirt and stone) randomly generated to create a world consisting of biomes containing plains, mountains, caves, deserts and bodies of water (see Figure 1) (Short, 2012). To all purposes, this world is infinite, since it keeps generating as you walk. Players can gather materials and either place them in the world to create various constructions or use them to craft various items. The game play also includes the use of electrical circuits and logic gates which function much like their real-world counterparts (Short, 2012). The game’s blocky appearance is a visual allusion to LEGO™, and suggests a space in which the player is given free rein to create whatever he or she wishes from the pieces provided (Duncan, 2011). The game can be played in either one of two modes: 1) ‘survivor’ mode, in which resources are limited, the players are attacked by aggressive ‘mobs’, and health and hunger must be maintained at acceptable levels; or 2) ‘creative’ mode, in which the building materials are infinite and the player does not need to worry about health. In addition to these game modes, players can access multiplayer, shared *Minecraft* servers where they can interact with other players.
Minecraft is a game in which the players are not simply consumers, but are also active in developing and changing the game. Since its inception, Minecraft has been ‘agile’ in its development, including customer collaboration as an explicit element in its construction (Duncan, 2011). Players are used as live testers of the game, open conversations are had about the game’s design between players and the game’s creator, and players are encouraged to modify (mod) the game and share their modified versions with the Minecraft community (Bayliss, 2012; Duncan, 2011). ‘Modding’ has added another level to the usual game play involved in digital games. Players now have the ability to not only interact with the world of the game, but also to change it according to their wishes. This has resulted in the formation of many thriving communities around the game of Minecraft such as instructional websites, wiki pages, discussion boards in which players share creative constructions within the game, and YouTube tutorials, which all employ social learning to further players’ understanding of the game (Banks & Potts, 2010; Bayliss, 2012).

Since its release in 2009, Minecraft has become one of the most popular digital games in the world (Alex, 2013), with over 19 million people having bought the PC and Mac version of the game since its release in 2009 (Mojang, 2015). Interestingly, it seems that Minecraft is a gender neutral game. According to Alexa (http://www.alexa.com/), a company which provides commercial web traffic data, the number of females who visited the Minecraft website over the last year was greater than the number of males. A survey conducted in the US discovered that the number of females and males that play games in America is almost equal (48% female, 52% male) (Entertainment Software Association, 2014). These findings suggest that introducing Minecraft in educational settings will not alienate females from the lesson, and may in fact
engage females in subjects in which they are traditionally underrepresented (e.g., math and physics).

*Minecraft* is a game that seems to have struck a chord with many people over a short period of time, and this popularity could mean that potential students will be motivated and engaged by the inclusion of a familiar game in their educational experience.

![Minecraft Screenshot](http://dylrocks95.deviantart.com/art/Minecraft-Screenshot-Ocean-210050937)

*Figure 1. Screenshot of a typical scene in a Minecraft simulated world (http://dylrocks95.deviantart.com/art/Minecraft-Screenshot-Ocean-210050937)*

**Is Minecraft a “Good” Game?**

Before we can decide if *Minecraft* is a game that can be used to educate students, we need to see if the game design demonstrates positive principles of learning. In other words, is *Minecraft* a good game? To do this we can compare it to the “checklist” on Table 1 to see how many of these features are present in the game. This has been done in Table 2, and the results are that *Minecraft* exhibits most (if not all) of these learning principles. This means that not only is *Minecraft* an engaging and entertaining game, but it also provides difficult challenges for players.
to overcome, which compels the players to learn and master the game. This suggests that

*Minecraft* has the potential for use in educational contexts.

Table 2
*Learning Principles present in Minecraft (adapted from Gee, 2004)*

<table>
<thead>
<tr>
<th>Principle</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Co-Design</td>
<td>In <em>Minecraft</em>, players can change the world around them as they see fit. They can also create their own versions of the game through modding.</td>
</tr>
<tr>
<td>Customize</td>
<td><em>Minecraft</em> allows for different modes of play within the game, and many of the different mods allow for very different styles of play.</td>
</tr>
<tr>
<td>Identity</td>
<td>Players can customize their characters and environments to a great extent, so that it is easy to create deep and consequential stories and histories in the game world for the characters they play.</td>
</tr>
<tr>
<td>Manipulation</td>
<td>Digital games inherently involve action at a (albeit virtual) distance. <em>Minecraft</em> offers the player intricate, effective, and easy manipulation of the world’s objects, which become tools for carrying out the player’s goals.</td>
</tr>
<tr>
<td>Well-Order Problems</td>
<td>The tools that you craft in <em>Minecraft</em> start from simple tools for survival and increase to more complicated tools for creation of complex structures (e.g. logic gates). Thus the problems are well-ordered.</td>
</tr>
<tr>
<td>Pleasantly Frustrating</td>
<td>Not only does <em>Minecraft</em> have different difficulty levels, but it is also very easy to learn from mistakes since your character can never “truly” die – you always come back and remember what not to do next time.</td>
</tr>
<tr>
<td>Cycles of Expertise</td>
<td>While this is not inherent within the game of <em>Minecraft</em>, the different mods allow for the rules of the game to be changed, thus challenging the players which have already mastered other versions of the game.</td>
</tr>
<tr>
<td>Information “On Demand” and “Just in Time”</td>
<td><em>Minecraft</em> is a very intuitive game and can be learned easily without reading a manual or too much preparation ahead of time. The game provides information in forms of visual and auditory clues when the players need it.</td>
</tr>
<tr>
<td>Fish Tanks</td>
<td>The “creative mode” in <em>Minecraft</em> allows the player to experiment with all aspects of the game without risk of dying, and gives them unlimited resources.</td>
</tr>
<tr>
<td>Sandboxes</td>
<td><em>Minecraft</em> is described as a “sandbox game” and is a good simulation of the real world.</td>
</tr>
<tr>
<td>Skills as Strategies</td>
<td>In <em>Minecraft</em> players need to learn skills in order to survive in the world. They need to find food, shelter and resources.</td>
</tr>
<tr>
<td>System Thinking</td>
<td><em>Minecraft</em> gives players a good feel for the overall world and game system they are in. It allows players to develop good intuitions about what works and about how what they are doing at the present moment fits into the trajectory of the game as a whole.</td>
</tr>
<tr>
<td>Meaning as Action Image</td>
<td>The whole world of <em>Minecraft</em> is a world of actions and experience. The possibility of creating different mods means that the experiences the players can be subjected to are limitless.</td>
</tr>
</tbody>
</table>
Minecraft in Education

The use of *Minecraft* as an educational tool is not a new concept. In 2010, Joel Levin created a blog named *The Minecraft Teacher* (http://minecraftteacher.tumblr.com/), in which he detailed his experiments using *Minecraft* as an educational environment for his elementary students (Duncan, 2011). This garnered enough attention from both the gaming and education community, which eventually led to the creation of an educational mod for *Minecraft* (https://minecraftedu.com/). *MinecraftEdu* is made specifically for classroom use and has been used by over 3,000 teachers in over 40 countries to teach subjects such as Science, Art and Language (TeacherGaming LLC, 2015). *Minecraft* has also been used in college settings, for example to teach logic operations (Duncan, 2011) or game artificial intelligence (Bayliss, 2012).

*Minecraft* especially lends itself to science education. It uses cubic geometry, contains a functioning ecology, and has chemistry and physics aspects interwoven within the game, which can all be used to develop the scientific literacy of players (Short, 2012). There is a foundation of resources with a vibrant community that deals with education in *Minecraft*, so that creating a new type of lesson will not be such a daunting task. There is much support on the Internet in the form of wiki forums (http://minecraftinschool.pbworks.com), google groups (https://groups.google.com/forum/#!forum/minecraft-teachers), and communities of teachers that are exploring ways of implementing *Minecraft* across the curriculum (http://massivelyminecraftproject.org/).

*Minecraft* is a game that is heavily entrenched in gaming culture (Duncan, 2011), and whose use as an educational tool across subjects and settings has increased drastically since its release (Short, 2012). It is an entertaining and engaging game which has attracted millions of people from across the world, and is already being used to illustrate scientific concepts in
classrooms globally (Short, 2012). The game has a developmental learning curve and a flexibility that has made it possible to implement it at many educational levels, ranging from elementary school to college (Duncan, 2011; Short, 2012). In short, the game of Minecraft seems ideally suited for engaging students in learning science content in an educational context.

**Conclusion**

Lack of student engagement in science education is a problem that many schools and teachers face in their classrooms. I have shown here that DGBL has the potential to not only address the problem of motivating and engaging students in learning science, but can also help engage students in problem-solving, promote collaboration and help students learn specific science concepts. DGBL is expressed in the “language” of the digital native learners, and is thus immediately more approachable and easier to learn. Good digital games embody and are grounded in concrete learning principles and theories, which help challenge students to learn, and yet keep them engaged. It is thus no surprise that the use of DGBL within education has become more widespread over the last few decades.

Minecraft is an ideal conduit for use in science education due to its increasing popularity, science-based game-play mechanics and online support for educators. It exhibits many of the properties of a good digital game, which means it can challenge students and engage them in learning. With its ability to be adapted to what people want (through modding), Minecraft seems to have unlimited potential for uses in science education. Since it is gender-neutral, Minecraft also has the potential to engage more females in science education or at the least will not discourage females from participating. In conclusion, DGBL and specifically Minecraft should be used as a platform to engage students in learning science.
The Next Step

This paper has discussed the opportunities for using DGBL in education, and has argued for the implementation of Minecraft in science classrooms. However, this is only the first step in a long journey. I have explained why DGBL is engaging and effective, and what aspects of digital games make them good games for learning. The next step is to explore how games can be integrated into the learning process to maximize their learning potential, and how to educate our teachers so that they have the technological pedagogical content knowledge necessary for implementing DGBL.

I believe that with an instructional support framework and explicit instruction Minecraft has the potential to be an effective instrument for teaching science in schools. This might be a difficult undertaking however, as teachers who are digital immigrants may not want to associate themselves with the gaming culture. In order to bring DGBL into the classroom, teachers will need to experience it themselves and get the skills needed to use it effectively in their classrooms. This might be done through introductory DGBL courses in teacher education programs, or through Pro-D events. In any case, it is evident that this topic requires further investigation, specifically research on how to educate teachers in the use of DGBL.
References


