The Role of New Technologies: The Educational Effectiveness of Video Games, Simulations, and Virtual Reality in the Science Classroom

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Abstract
With the recent advancement of technology, more schools are starting to integrate ICT into their curricula. This review looks at the effectiveness of this integration regarding video games, simulations, and virtual reality, and their role in science education. Numerous benefits were found relating to student engagement, attitudes towards science and in the development of 21st-century skills such as creativity and problem-solving. However, there were inconclusive results regarding the academic potential gained from these tools compared to more traditional science teaching methods. Overall, it was found that the teacher's pedagogy surrounding technology was the key factor in determining whether the ICT tool resulted in significant learning gains.

Keywords: *Digital-technology, Science education, video games, simulations, virtual reality, game-based learning*

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Introduction
Traditional teaching methods of stating facts verbally, projector presentations, and visualisation on a whiteboard are inherently static in nature, and do not require student input or interaction (Bibek & Deb, 2016). Using these techniques, learner attention and engagement can be easily lost over extended periods of time. User-focused information and communication technology (ICT) allows for first-person experiences, which involves active engagement from the learner.

In recent years, the availability and access to laptops and other ICT devices have led to their gradual integration into the science classroom (Rutten, van Joolingen & van der Veen, 2012). However, workbooks and textbooks remain the primary resources for teaching in most schools today (Barab et al., 2009). Trying to understand science from a textbook, is like trying to learn how to play a video game from solely reading the game manual, where there is an abundance of information with limited to non-existent context.

Many processes in chemistry and biology occur on a microscopic scale, such as chemical reactions and protein synthesis, while earth and space science concepts require a macroscopic scale. This is a common reason why science is often difficult for learners to comprehend properly (Pekdağ, 2010). Through the use of ICT, and in particular, video games, simulations, and virtual reality, students change the scale of these processes to start recognising their own misconceptions, and start to build accurate mental models that will contextualise scientific information.

Video Games and Game-Based Learning
Game-based learning describes the knowledge and skills acquired by the student through problem-solving challenges in the context of a video game environment (Qian & Clark, 2016). Through game-based learning, video games promote 21st-century skills such as creativity, collaboration, communication, and critical thinking (Qian & Clark, 2016). These skills are important for learners to obtain as they transition into the post-schooling world. In recent years, educators are moving away from teaching only subject content knowledge, and are now aiming for cross-curricular content that nurtures 21st-century skills. In contrast, traditional educational methods often minimise these skills by favouring high-stakes individualistic standardised testing (Qian & Clark, 2016). Video games compliment science education as it contextualises many of the complex phenomena that are currently in the curriculum (Barab et al., 2009). The virtual gaming world has the benefit of having readily manipulated variables, such as chemical composition, the force of gravity, and the direction and speed of time, as well as different representations of scientific concepts like atoms and cells. They have interactive and learner-led storylines with complex interacting mechanics which can lead to substantial learning potentials. Unfortunately, given all these possible benefits, video

games are still stigmatised by some educators; being perceived as just entertainment and having no value for educational purposes in the classroom (Annetta et al., 2013).

Educational video games create a “low-stress environment” (Marino et al., 2013) where learners can interact with more accessible versions of complex scientific vocabulary, concepts and ideas. Teachers can use these video games in the design of a universal design for learning (UDL) curriculum which is made to suit all learners, including students who may be hindered by learning difficulties. Students with learning difficulties are more likely to hold negative dispositions towards science (Marino et al., 2013). This is due to the vast amount of complex reading and text in the subject which limits their ability to meaningfully understand and comprehend the scientific information. New vocabulary and ideas are often presented to the students through inaccessible media, instead of through UDL techniques. As a result, struggling learners may fall further behind until they leave the subject altogether. This can result in secondary science in schools becoming a test of reading comprehension rather than an active exercise in experimental inquiry (Barab et al., 2009).

In a study of 57 middle school students with learning difficulties, three educational video games were played by the students, and the learning gains experienced were analysed using standardised pre-post testing versus more traditional ‘pen and paper’ methods (Marino et al., 2013). The quantitative results from this study supported the notion that the gaming units were of no benefit to students with learning difficulties compared to traditional teaching methods (Marino et al., 2013). These results were also supported by Annetta et al. (2013) who found no difference in academic student performance when using games to review a genetics unit compared to ‘paper and pencil practice’. However, the qualitative feedback from both studies showed students reporting higher levels of engagement and understanding the information content when using video games. The students were collaborating with their peers on the games; sharing and explaining the games to their friends and family, and teaching the content to others. For example, a quote by a student was: “I played the game at home with my dad, he was excited about the bacteria game.” These games captivate and excite students enough to spend hours of their own time outside of the classroom learning on their own (Annetta et al., 2013). Educational games can create lifelike experiences and assist in the creation of active context-based learning. Students reported making connections between what they experienced in the games, and the real world, for example, “It's a lot like the store where my mum works, so it seemed real” (Marino et al., 2013). This is a key step in bridging what students experience outside of the school to what they are currently doing and learning in the classroom.

What Makes an Effective Educational Video Game?

Annetta et al. (2013) found that video-games need to be educational by design, with a focus on instructional content, and less on visual animation and audio. An example of a purpose-built educational game is Taiga Park designed by Barab (Barab et al., 2009). Taiga Park is a multiplayer virtual environment which allows users to explore, problem solve and interact with non-player characters (NPCs). In this purposefully designed world, the student becomes the protagonist who has a form of agency using their own virtual avatar. They are in control, and they take responsibility for the consequences of choices made in-game to progress the storyline. In a study of 51 university undergraduates, it was found that the group assigned to the virtual world Taiga Park, performed significantly better on a post-test evaluation, compared to the group given more direct focused information by traditional texts (Barab et al., 2009). This was surprising as the gaming group had to implicitly infer the educational concepts from their gaming experience for the test afterwards.

A multi-variable study (Israel, Wang & Marino, 2016) analysed the performance of 366 middle school students in three science-based video-games. What they found was that post-test scores were significantly influenced by three main factors, namely, reading ability level, previous subject knowledge, and self-perceptions about scientific capabilities. The researchers found that, much like the classroom environment, learners enter the gaming environment with varying levels of confidence, prior knowledge and self-deterministic attitudes. Teachers and educators need to be able to assess these factors to decide on the most effective ICT tools to implement in their practice (Israel et al., 2016).

Simulations

Computer simulations are designed purposefully to assist in the facilitation of teaching and learning through visualisation. In the science classroom, they offer a wide range of simplified, dynamic, user-focused model representations of natural processes and experiments that could not otherwise be performed in a school environment (Sarabando, Cravino & Soares, 2014). In chemistry, some reactions are either too dangerous or too time-consuming for students to carry out on their own. However, they still have an immense academic value associated with them, so a simulation can be used to show the reaction while avoiding the risks or costs of doing them (Pekdağ, 2010).

When compared to traditional textbooks and whiteboard presentations, computer-based simulations create a stress-free environment where learners can change the time-scale of events. This allows the user to explore hypothetical situations at their own pace without fear of judgement by their teacher and peers (Rutten et al., 2012). Additionally, a simulation allows for the precise control of each parameter and variable of a system individually, which might not be possible to achieve in real life (Yaman, Nerdel & Bayrhuber, 2008). This lets the student actively control the final product of the simulation and focus the student’s attention on the desired phenomena, or cause-and-effect relationship (Sarabando et al., 2014).

A study investigating the effectiveness of computer simulations in physics, replacing traditional hands-on experiments (Sarabando et al., 2014) was conducted. A total of 142 middle school students were split into two groups: one group had a 90-minute session with a computer simulation; the other group did a physics lab experiment with written instructions. The results of the study showed that the use of computer simulations helped the students better understand the physical concepts of weight and mass. Analysed using a standardised pre- and post-test, the group accessing the computer simulation reported learning gains of 40-58%, whereas the control group who performed experimental lab activities, their total gains were only 20-37%, which was significantly lower. These results support the notion that interaction with digital simulations can effectively contextualise the core concepts in science that are traditionally presented to students through symbolic notion (Sarabando et al., 2014).

The effectiveness of a computer simulation depends on the teacher's role in its implementation (Sarabando et al., 2014); some teachers think that the simulation will be taking over their teaching responsibility (Pekdağ, 2010). Teachers need to be provided with concise explanations as to what their role is in providing instructional support with regards to ICT and simulations.

A challenge with giving verbal feedback or instruction to the student (e.g., "Try changing this parameter...") is it can be damaging to the learner's agency; it can be seen as an attempt to limit the student's personal control over the simulation (Lindgren, Tscholl, Wang & Johnson, 2016). While working with simulations, having instructional support tasks embedded in the programme can help the learner identify the simulation's educational learning objective explicitly, without feeling as if the teaching is directly telling them the steps to take (Yaman et al., 2008). Another challenge arises when simulations try to replace all real-world experimental lab work, meaning the student will lack competent laboratory skills which are often the learning intention behind doing experiments. However, limited use of simulations can make lab work more effective by having it as pre-lab training (Rutten et al., 2012).

Virtual Reality

Virtual reality (VR) is a first-person interactive computer-generated experience within a simulated environment. Unlike video games and simulations, which both use mainly audio and visual prompts, VR uses the user's own movements and gestures to interact with the virtual world. From an educational standpoint, interacting in virtual reality creates conceptual anchors from which new knowledge can be built (Lindgren et al., 2016).

Currently, the use of VR in classrooms is almost non-existent, which is surprising given the technology's potential as a valuable learning tool. Different versions of VR can be readily accessed by learners using a smartphone with an internet connection. Many schools already have a 'bring your own device' policy in place, with most students having access to a smartphone (Bibek & Deb, 2016), therefore, it is not a lack of technological access stopping the implementation of VR.

The importance of place-based learning has already been well established in the literature (Johnson, 2011). VR makes place-based learning more accessible, costing less time and money, as educators can take their classes anywhere in the world using their own devices. In a worldwide trial organised by Google in 2015, selected schools were given cardboard VR headsets which students could use with their own phones. With these headsets, learners went on guided virtual journeys of educational sites and landmarks such as space stations, coral reefs, museums, laboratories and volcanoes (Bibek & Deb, 2016). During these guided virtual journeys, the teachers could lead the students while they are experiencing VR through a separate tablet, highlighting the relevant places and details the students should focus on.

Bibek and Deb (2016) conducted a study of 40 university undergraduates over a two-month period on varying aspects of computer science. Their study involved two groups: a control group being taught with textbooks and a whiteboard, and an experimental group with VR headsets. Over 16 sessions, both groups' learning gains were assessed using pre- and post-testing. Initially, the control group performed better with traditional teaching methods than the VR group, however, as the VR group got used to using the headsets, the VR group ended up testing significantly and consistently better than the control group towards the end of the study (Bibek & Deb, 2016). Physical activities seem to more effectively focus the learner's view of science as being relevant to the real-world (Lindgren et al., 2016).

In a study of middle school students, an experimental group of 58 students experienced the game MEteor, an interactive and immersive virtual simulation of physics and astronomy. The experimental immersive group reported significantly higher levels of enjoyment and received significantly higher scores on a post-test than those in the desktop control group, in addition to fostering a more positive attitude towards science and education in general. Overall, the researchers found that the immersive full-body simulation led to the learner feeling more connected to the subject content (Lindgren et al., 2016).

The Limitations and Challenges Surrounding ICT Tools

The biggest barrier to ICT integration in the science classroom is the failure of educators to incorporate the technology effectively into their teaching and learning pedagogy (Pekdağ, 2010). Only providing the means of access to devices and software without attention to learner support and instruction, does not result in student learning and the desired conceptual gains (Sarabando et al., 2014). In response to this, teachers should be provided with up-to-date education on ICT integration with concrete examples if their students are to receive the most benefit from using these tools (Pekdağ, 2010). Pre-service teacher education programmes need to cover the integration of technology in practice, as this has been shown to improve in-service confidence and effectiveness using various ICT tools (Lee & Lee, 2014).

The design of ICT tools is important in determining how effective a teaching resource it is, as some video games, simulations, and virtual reality programmes have a high 'cognitive load' defined as the mental effort required to understand a concept in an individual's mind (Pekdağ, 2010). Conversely, 3D simulations have been found to be detrimental for learners conceptualising information. The simulation was unfolding too quickly and presenting too much visual information at one time. This caused extra cognitive load for students, which lacked the spatial ability to comprehend the simulations completely (Vavra et al., 2011). Educational ICT tools should be learner-focused by design to not create a cognitive overload for the student, due to learning and memorisation being hindered by extreme cognitive loads (Pekdağ, 2010).

Conclusion

The role of new technologies in the science classroom is still being investigated. What has been found is that technology engages students in the learning process, and can result in significant learning gains when used appropriately. The effectiveness of integrated ICT tools in science education is a direct product of the interplay between the ICT tool, the learners and the teacher. Without adequate teaching skills and training for teachers to incorporate technology into their teaching and learning pedagogy, the full potential of video-games, simulations, and virtual reality as a teaching resource may remain out of reach (Sarabando et al., 2014).

There is still much research to be done in this area, particularly regarding senior high-school science. The literature appears to focus on junior and university science, as there is more flexibility in the curriculum for research during this time (Annetta et al., 2013). There is also a need to get students' input regarding what they think will work for them as they are the target audience. Longer-term studies are also needed – with most of the literature focusing on students having one short session with an ICT tool – because learning gains will be more apparent when students are comfortable and familiar with the technology which they are using.

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