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Virtual Engineering in Minecraft: Helping Students Visualize and Manipulate the Properties of Materials

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ABSTRACT

Due to limited laboratory facilities and other constraints, many engineering students may not have the opportunity to engage with practical, hands-on learning experiences. Although some research suggests that game-based learning can provide students with these pedagogical benefits, much of that work does not directly assess the impact of such games on student learning outcomes. This paper examines the impact of leveraging a game-based virtual lab in an advanced, college-level engineering course on material properties. We compare learning outcomes derived from course content experienced in the virtual lab versus traditional classroom and homework formats. Students completed classroom activities and assignments in the virtual lab space for approximately half of the course content throughout the semester. Learning was assessed on three separate exams, each featuring content associated with the virtual lab, as well as content associated with traditional classroom and assignment formats. Our analyses compared student performance on both types of exam content. Students scored significantly higher on exam items corresponding to content learned using the virtual laboratory space compared to exam content learned only through traditional classroom and homework formats. Our results are consistent with prior work on game based learning in engineering and contribute to the existing research by providing a direct assessment of students' learning with the game-based experience, suggesting that game-based learning can, indeed, improve learning outcomes in this context. This particular virtual platform in question (*Minecraft*) is highly versatile and may offer further opportunities for adaptation and classroom research. While our data supports these conclusions, we acknowledge this is just a single study with a small sample size and features carefully selected topics that were covered in the Minecraft exercises.

Key words: Games, Engineering, Student assessment, Minecraft

INTRODUCTION

Research on the use of games as an educational tool has increased in recent years, leading to an ever-growing, more coherent body of literature that aims to document the potential benefits of their educational use and uncover the mechanisms that drive their efficacy (Boyle, Hainey, Connolly, Gray, Earp, Ott, Lim, Ninaus, Ribeiro, & Pereira, 2016; Dondlinger, 2007). Although solid evidence supports the idea that games can be leveraged to enhance learning outcomes (e.g., Lee, Luchini, Michael, Norris, & Soloway, 2004) and even solve real world problems (McGonigal, 2011), there is still much we don't know about multimedia design principles for effective learning (Clark & Mayer, 2016), especially as they apply to virtual games. In part, this gap is due to the broad use of the term "educational game". One of the most popular genres of educational game is a simulation, or virtual environment (Connolly, Boyle, MacArthur, Hainey, & Boyle, 2012). A simulation is essentially a program that aims to create a representation of reality or of a known process or phenomenon (Deshpande & Huang, 2011). Simulations can allow for experimentation in realistic, yet fictitious, low-stakes situations that expose students to a variety of possible outcomes that simply would not be realistic to achieve in a traditional lecture classroom, or even a modern laboratory (Lean, Moizer, Towler, & Abbey, 2006).

Broadly speaking, there is a multitude of research that provides evidence for the efficacy of simulations, and computer aided instruction in general, as pedagogical tools (Vogel, Vogel, Bowers, Bowers, Muse, & Wright, 2006). More specifically, however, there are finer distinctions to be made that are important to consider when we claim that simulations have been shown to successfully enhance learning outcomes. For instance, Sitzman, in her (2011) meta-analysis, outlined several characteristics of computer-based simulation games that have been shown to enhance learning outcomes, such as the conveyance of course material through active learning (see Freeman, Eddy, McDonough, Smith, Okoroafor, Jordt, & Wenderoth, 2014), and when the game is supplemented with other instructional methods, such as lecture (i.e., the game was not the sole mode of instruction). In addition, Lean, and colleagues (2006) outline several subtypes of simulations that differ in their composition and utility. Of particular interest to this research, are computer simulations that aim to replicate system characteristics with the use of object representations. The learning benefits of these particular types of simulations have received empirical support across a range of disciplines, including engineering (Lean et al., 2006).

As a general trend, the use of games to enhance learning in undergraduate engineering programs has been on the rise over the past two decades (Bodnar, Anastasio, Enszer, & Burkey, 2016). With the globalization and advancement of technology, simulation games have received particular attention for their potential to maximize engineering students' application of academic knowledge to real world settings (Deshpande & Huang, 2011). Indeed, as Hauge, Pourabdollahian, and Riedel (2013) point out, the skills required for engineering students entering the workforce are becoming ever-more complex and dynamic, making them excellent targets for augmentation with practice using virtual simulations. Although there are multiple case studies of such games that have been carried out in engineering education (Bodnar et al., 2016; Davidovitch, Parush, & Shtub, 2006; Hauge et al., 2013), the majority of the research in this area lacks a systematic assessment of learning outcomes. In a recent review, Bodnar et al. (2016) found that most published papers on the pedagogical use of games in engineering focused solely on student attitudes, and even among those that did consider student learning, many lacked important components such as comparison groups and the use of inferential statistics. With the present research, which is a collaboration between engineering research faculty and educational researchers, we hope to contribute by providing empirical support for the presumed learning benefits provided by the implementation of a simulation-based game in an undergraduate engineering course.

A particular simulation game that has garnered much attention in the educational community in recent years is Minecraft (https://minecraft.net/). Minecraft is what is known as a 'sandbox' building game, where players can have complete freedom in how they choose to play the game and navigate their virtual environment that is based on the real world. There are no missions or levels, and the gameplay does not feature a predetermined linear progression that is often found in other computer games. The foundational principle of Minecraft is creation; players can use different materials with varying levels of complexity to build virtually anything. Moreover, the educational use of Minecraft has been a well-documented area of research all on its own (see Nebel, Schneider, & Rey, 2016 for a review). Minecraft is capable of teaching advanced scientific concepts, yet is simple enough for small children to play. As for its applicability for learning in STEM, Short (2012) highlights the educational potential of the Minecraft universe for numerous scientific disciplines. His work illustrates how elements of the Minecraft interface can be manipulated and constrained to focus on a wide variety of educational goals, and he refers to Minecraft as "a game-changer in the field of science instruction".

In addition to Short's (2012) enthusiastic endorsement, Smaldone, Thompson, Evans, and Voit (2017) also demonstrated Minecraft's versatility as an educational tool by creating a modified version of the game (known as a "mod"), called *Polycraft World*. Beginning with a basic Minecraft license, which is relatively cheap and is available for anybody with a working computer that has a keyboard and a mouse, Smaldone et al. (2017) customized the content of the game so that the materials the players use have the properties and behavior of the chemistry and engineering content that would be ordinarily presented in a course. Students were able to freely interact and experiment with these materials, which afforded them a unique opportunity to learn disciplinary content and become familiar with real world material properties.

For the present research, building on Smaldone and colleagues' (2017) approach, we created our own customized Minecraft content to use in a college-level course on materials and their processing offered as part of the mechanical engineering curriculum. When this new course was proposed, laboratory facilities for hands-on, experiential learning were not readily available. In part, this motivated our exploration of Minecraft as an educational resource. Could it replace learning experiences that typically occur in engineering laboratory learning environments? Could it create new learning opportunities that were not possible in the traditional engineering classroom or laboratory? Consequently, our goal was to strategically deploy Minecraft as a technology-enhanced learning resource throughout the semester in an upper-level mechanical engineering course on materials properties and assess student learning as it related to that experience. Specifically, would students learn more from course units leveraging Minecraft as a learning resource compared to units in which Minecraft was absent?

METHODS

The Course and Students

We implemented game-based modules in Materials and Their Processing for Mechanical Engineers, an upper-level, undergraduate course in Mechanical Engineering. It was offered for the first time during Spring Semester 2017 at a mid-sized, Midwestern, research-intensive university in the United States. One of the authors of this manuscript taught this course as the instructor of record. This 14-week, full-semester course held lecture twice per week for 90 minutes each. The materials course, which is an elective in the Mechanical Engineering Department that focuses on the properties and performance of engineering materials and understanding concepts such as crystal structures, defects, diffusion, and phase equilibria. In particular, students were tasked with understanding how processing can change the way materials assemble and lead to differences in properties, such as mechanical behavior and strength.

Fourteen undergraduate seniors, all engineering majors, enrolled in this course and participated in the study. The frequency breakdown of student demographics is as follows: male (10), female (4), and identified as White (7), Black (4), Asian (2), and unreported (1). In terms of these demographics, this sample is slightly more diverse than the population of students in the Mechanical Engineering Department or our university's student population at large.

Developing Game-Based Course Topics

Although the older Minecraft version used in the course required a license fee, Minecraft's current educational version is free and allows instructors to make modifications and incorporate specific course content. Some Minecraft modules developed for this course also used the Polycraft mod, developed at the University of Texas at Dallas (Smaldone et al., 2017). These modules were especially useful for teaching students about processing materials such as polymers and plastics. A team of five undergraduate research assistants worked with the instructor and a graduate student over the course of one year to create and pilot test the course materials using Minecraft. These materials correspond to four major topics from the widely used introductory materials science textbook by Callister and Rethwisch (2014). The targeted topics were atomic structure and interatomic bonding, structure of metals and ceramics, imperfections in solids, processing of ceramics & polymers (Table 1). We selected these particular topics because they feature concepts

Table 1. Course timeline regarding the sequence of topics, class sessions, Minecraft use. Four of fourteen topics integrated the use of Minecraft into class activities and homework.

Topic	Number of class sessions	Minecraft used?
Atomic Structure and Interatomic Bonding	2	Y
Spectroscopy and EDS Techniques	1	N
Structure of Metals and Ceramics	2	Y
X-ray Diffraction	1	N
Imperfections in Solids	2	Y
Optical and Electron Microscopy	1	N
Diffusion	2	N
Phase Diagrams	4	N
Diffusion	2	N
Solidification	1	N
Elasticity, Plasticity, and Strengthening Mechanisms	1	N
Heat Treatment and Phase Transformations	1	N
Processing of Ceramics and Polymers	3	Y
Electrical, Thermal, Magnetic, and Optical Properties	1	N
Fracture and Failure, Thin Films	1	N

that can be challenging for students to grasp, and their specific contents aligned well with the capabilities of the Minecraft platform. We also sought to distribute the use of Minecraft modules evenly across the semester, so it was not the case that we simply selected the most difficult topics overall. The remaining topics that are covered in the textbook, but not by Minecraft modules, are still quite challenging.

Our goal with the modules was to give the students enough scaffolding to keep them on track, but also to provide enough user autonomy for students to learn by exploration and discovery. Students' activities in the modules included unique opportunities to engage with the course content and do things that they were not otherwise able to do during class or on traditional homework assignments (i.e., problem sets). The typical module featured a 'virtual-classroom' setting, designed by the instructor, which contained various materials that pertained to the specific chapter. In this setting, students had the freedom to explore the materials however they liked. Content was not sequenced linearly and students were not constrained to engage with the current chapter of content only. For example, students could "walk" around and explore a model of a crystal structure and visualize and interact with the content in three dimensions (Fig. 1a,b), have the ability to assemble materials into devices like batteries (see functioning prototype of a Tesla Gigafactory in Fig. 1c), build using different materials with in-game processing tools like the machining mills and injection molders (Fig. 1d,e), and were given creative latitude to complete in-game homework assignments that had multiple potential solutions (Fig. 1f).

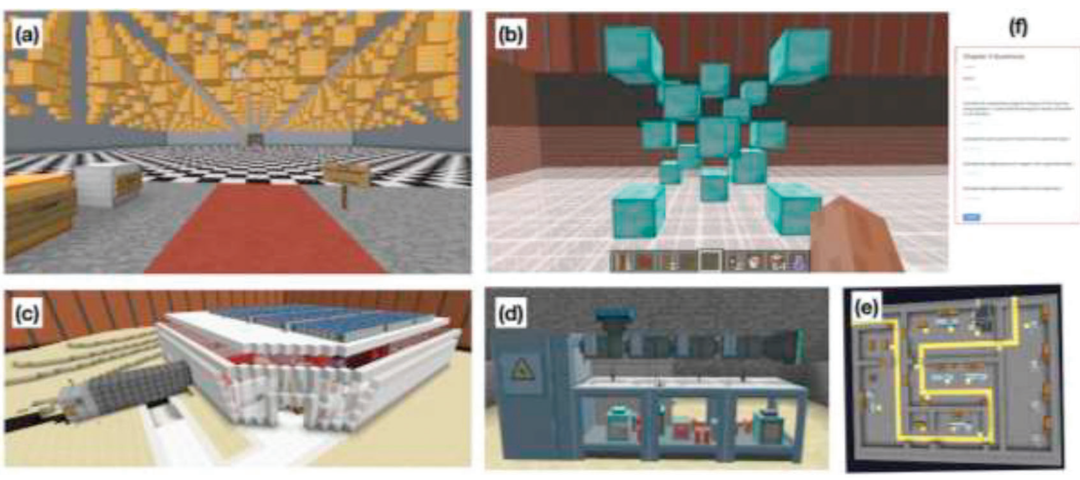

Figure 1. Screenshots of representative activities from Minecraft modules used in the course.

Implementation (Procedures)

During four distinct topical units spaced throughout the course, students were given access to the Minecraft module that corresponded to the current course topic. Students had access to these modules throughout the course. Prior to units using Minecraft, for an entire lecture session, we conducted a set of tutorial exercises to help students learn to navigate Minecraft and its features. Additionally, we created YouTube channels for the course, containing several short instructional videos to guide students through all aspects of the game, from installation to advanced creative mode controls and navigating the virtual learning content. All YouTube videos can be found using the links found in the references section. We hosted the Minecraft modules on a dedicated server to allow interactions between students and instructor beyond typical class hours. These tutorial exercises and videos aimed to normalize the difference between novice and expert Minecraft users as well as to provide an inclusive experience for all students whether or not they were previously exposed to the game.

The average length of a course topic (i.e., textbook chapter) was two lecture sessions. Each topic featured its own homework assignment. These sets of questions and problems required students to apply materials science concepts. For non-Minecraft topics, students received traditional lectures during class sessions, then students completed homework assignments using only traditional resources (e.g., the course textbook) and submitted them on paper. For Minecraft topics, during class sessions, students experienced a combination of lecture and Minecraft activities. Afterwards, they could use the Minecraft modules as a resource while completing homework assignments, and actually completed and submitted the assignment through the Minecraft interface.

Our aim was to evaluate the effectiveness of teaching advanced engineering concepts using the Minecraft game, relative to using traditional course activities. We tested this question using a within-subjects study design using student exam performance as our dependent variable. Each topic of the course had an accompanying Minecraft module or did not. Consequently, over the course of the semester, students experienced both study conditions and served as their own experimental controls. At any given time in the course, all students were experiencing the same conditions (see Table 1 for the sequence students experienced). Overall, students experienced four topics incorporating Minecraft, and ten topics that did not. Given the findings from the research reviewed above, we predicted that students would perform better on exam content that corresponded to topics that used a Minecraft module relative to exam content from topics that did not use a Minecraft module.

Measures

To measure learning outcomes, we evaluated student performance on the course's three exams. The first two exams occurred at week 6 and week 11 of the 14-week semester, and the third exam occurred the week after the last class session, during the university's final exam period. Each exam contained 7-12

Table 2. Breakdown of the number of questions and possible points earned for content that was and was not associated with the use of Minecraft modules on all three exams.

	Minecraft		Control	
	Questions	Points	Questions	Points
Exam 1	6	80	2	20
Exam 2	2	15	5	85
Exam 3	6	65	7	55
Total	14	160	14	160

questions, which were primarily short answer questions with multiple components (see appendix for sample exam questions) that required students to apply their knowledge and solve problems quantitatively. For each exam, we coded questions according to whether they corresponded to content associated with a Minecraft module (Minecraft questions) or content that was not associated with Minecraft modules (control questions). For a breakdown of the number of questions and points associated with each condition on each exam, see Table 2. All exams for the course were scored by the instructor.

RESULTS AND DISCUSSION

Results

In total, across three exams, students were assessed on their ability to correctly solve 28 problems, 14 of which were designed to address content that was explicitly covered by the use of Minecraft as a pedagogical tool during the semester. For our dependent measure, we computed a percentage of total possible points each student earned for questions coded as being associated with Minecraft modules (MC) and questions coded as not associated with the Minecraft modules (control). Because the distribution of Minecraft and control content was not equal for each exam, we took the analytic approach of collapsing across all exams to achieve a more balanced comparison. Collapsing across all three exams, we compared the difference in student performance for each type of exam question. To test our main hypothesis, we conducted a paired-samples *t-test* to compare the mean performance on control questions to the mean performance on MC questions for all students in the course. Consistent with our hypothesis, the mean score on the MC problems ($M = 82.32$, $SD = 11.01$) was found to be significantly higher than the mean score on the control problems ($M = 72.28$, $SD = 9.51$), $t\ (13) = 4.38$, $p < .01$, suggesting an effect of enhanced learning for the Minecraft content. As our sample is relatively small, a non-parametric test (Wilcoxon Signed Ranks test) was also conducted to allay concerns related to potential departures from distributional normality or other parametric assumptions. The non-parametric test revealed results consistent with the parametric *t-test*, $z = 2.86$,

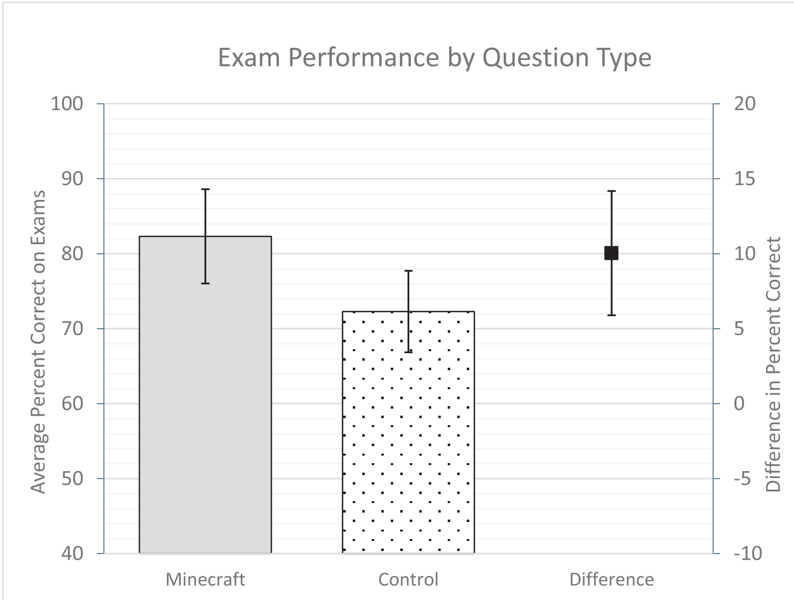

Figure 2. Average exam performance for all Minecraft vs. Control questions.

$p < .01$. The results of the *t-test* and the accompanying confidence intervals are depicted in Fig. 2. In addition, we calculated the effect size (Hedge's *g*) to be $g = .91$, suggesting a rather large effect. Speaking practically, an effect size of $g = .91$ would predict student performance to be almost a full standard deviation better for content covered by our intervention (see Fig. 2). Of note, the computation of our effect size included corrections for both the correlated error variance as a result of the paired samples design and the relatively small sample size (use of Hedge's *g* formula instead of Cohen's *d*). We also examined this difference at the exam level, comparing performance on control versus MC questions for students on each exam individually. These results are consistent with our results overall. Table 3 contains the descriptive statistics from each individual exam.

Table 3. Descriptive statistics for Minecraft vs. Control questions on all three exams.

	Question Type	N	Mean	Std. Dev.
Exam 1	Minecraft	13	77.26	15.72
	Control	13	73.46	18.19
Exam 2	Minecraft	14	80.71	26.52
	Control	14	70.33	14.99
Exam 3	Minecraft	14	88.10	9.90
	Control	14	73.62	12.27
Overall	Minecraft	14	82.32	11.01
	Control	14	72.28	9.51

Discussion

Much of the existing research on the use of games in engineering is focused on students' engagement or perceptions of their learning experience (i.e., indirect measures of learning). This study is noteworthy because it directly measures student learning outcomes. Moreover, it was conducted "in the wild", i.e., in the context of an actual Mechanical Engineering course with undergraduate students at research-intensive institutions.

Across three exams, we found that engineering students performed significantly better on content from units using the Minecraft game as a technology-enhanced learning tool, compared to their performance on all other course content. This result is promising because our Minecraft modules were specifically designed to replace some experiences that a student might otherwise gain in a laboratory section of a course and/or create learning opportunities that are only possible through simulation. Indeed, we had no comparison group of students that actually used laboratory facilities or both lab facilities and Minecraft. Therefore, we cannot directly assess the relative merits of Minecraft as a replacement or supplemental resource for labs. Nevertheless, there are aspects of the Minecraft game that are simply impossible to replicate in a physical lab space (e.g., interacting with materials at the molecular level in three dimensions). While mapping student engineering learning outcomes aligned with Minecraft features is beyond the scope of this paper, our data suggests that strategic use of Minecraft can enhance student learning, especially when laboratory resources for students are absent. Furthermore, although simulation games such as Minecraft may offer an adequate replacement or enhancement for certain laboratory experiences, we speculate that this is by no means the ceiling for their potential educational value. Given the dynamic nature of the Minecraft platform, the possibility of creating other interactive virtual experiences for students that align with learning outcomes not traditionally targeted by labs is quite conceivable.

In addition to showing a difference in the overall average exam performance, the superior exam performance for Minecraft-related content was consistent across all three individual exams. This finding speaks to the reliability of Minecraft as a pedagogical tool. It also demonstrates that our results were not driven by any one particular course topic or unit. The consistent performance also suggests that any learning curve or cognitive burden associated with being a new user of the Minecraft game was not significantly interfering with students' learning. It is possible, however, that familiarity with the game as the semester progressed did contribute positively to learning, as mean scores on Minecraft-related content appeared to improve on each successive exam, while performance on non-Minecraft content remained relatively stable throughout the semester. We hypothesize that higher exam performance on Minecraft content is due to students' enhanced ability to visualize, manipulate, and explore three-dimensional content (see Fig. 1a,b), compared to traditional modes of practice (e.g., drawing 3D structures on 2D paper or manipulating three-dimensional ball and stick models of molecules).

Although improvement on the Minecraft content over time was not statistically significant in this case, it would be an interesting question to address more explicitly in future research.

Based on our experiences, we offer the following recommendations to instructors considering the implementation of Minecraft or other virtual learning environments in their courses. First, identify and target course content that is best aligned with Minecraft's features regarding visualization and manipulation. While some topics are aligned to Minecraft's affordances, others are not. We targeted Materials Science topics that contained a 3D visualization component related to comprehension and application of fundamental concepts. Similarly, don't overuse Minecraft. Minecraft is not a solution to all teaching challenges and students can get bored of any single teaching approach, decreasing motivation. Additionally, logistically, instructors should be prepared for the time investment required to develop the Minecraft content and adequately support student users. Our students differed dramatically regarding their prior experience with Minecraft. Some were experts with years of experience. Others were novices, including students who have never played Minecraft. As instructors, it was difficult to find the right balance of activities, challenge-level, and support for both experts and novices. Instructors should anticipate the needs of novices and proactively provide support and resources. In addition to multiple classroom training exercises, we provided tutorial videos and Minecraft office hours to support novices outside of class sessions. Finally, implementing Minecraft in our course was non-trivial financially. Expenses included a dedicated server (and its maintenance), staff to develop, host, and support both the software and tutorial videos, and a teaching assistant to help support student users. Without investing in these resources, our implementation strategy would not have been possible or successful.

While our data supports the potential added value of Minecraft as a virtual simulation tools for learning engineering concepts and problem solving, this is just a single study (and see other limitations below). The need for more such studies that collect learning outcomes data to directly measure the potential impacts of game-based learning in engineering is well documented (see Bodnar et al., 2016). Bodnar and colleagues (2016) also point out that a potential limiting factor in this area is that much of the work is carried out solely by engineering faculty who do not necessarily have experience with or a background in educational research. Consequently, Bodnar et al. (2016) have called for more collaborations among engineering faculty and those with experience and background in educational research. With the present authors being a collaboration of engineering faculty and educational researchers at a university-level center for teaching and learning, we are attempting to answer that call. It is our hope that even with this relatively small contribution, we can encourage more engineering faculty to collect similar data in their courses, so that we may continue to make progress in understanding the use of virtual games in the engineering discipline.

Limitations

This study measured performance on engineering exams for content learned, in part, through the use of Minecraft and compared that to performance on content that was learned through more traditional mediums (e.g., pen and paper, lecture). Although performance was higher from course units including Minecraft, it is possible that the content associated with Minecraft was just easier to learn. However, we think this is unlikely, despite being a possible limitation of the within-subjects study design used here. Minecraft happened to be associated with some of the more traditionally advanced course concepts (Table 1). Nonetheless, it would be beneficial for future research to account for this issue with a different study design, such as randomized control treatment study or quasi-experimental study administered across multiple sections of a course taught by the same instructor, or a within-subjects study in which the presence/absence of Minecraft is counterbalanced across students and course units. In our context, none of these alternative study designs were possible, but one should note that these study designs also have conspicuous limitations (as do most common classroom research study designs).

Another limitation is that our use of the Minecraft game was given careful thought regarding its alignment with the content in this specific course. It is possible that its general use as an effective educational tool is not widely transferable to other areas in engineering. Further research examining the effectiveness of Minecraft in other engineering courses at varying academic levels would undoubtedly be useful, although the level of customization required in any given context is likely to be substantial. Perhaps with more research by engineering faculty, a relatively standardized version of Minecraft modules could be constructed for use across a wider array of courses and/or learning objectives. In addition, our study leaves open the issue of scalability. Given sufficient computer resources, it is conceivable that this intervention could scale well with larger groups, but with our small course size of only 14 students, we can only speculate at this time. Scaling up the use of a computer game for a college course would almost certainly come with its own set of issues related to things like training, troubleshooting, and supervision that may pose unique challenges that we did not encounter in our small course.

Lastly, we recognize that our small sample of only 14 students has its own set of limitations. In particular, small sample sizes are often associated with inconclusive results when there are no significant findings and higher rates of false-positives when there are (Forstmeier, Wagenmakers, & Parker, 2017). Notably, however, as Ioannidis (2005) originally pointed out and Forstmeier et al. (2017) address in their recent work, the limitations of small sample size as they pertain to false-positive findings hinge on an assumption of low statistical power. For a relatively large effect, such as $d = .9$, a sample size of only 12 is required to achieve what is typically accepted as adequate statistical power (80%) in a repeated measures/paired samples design. Although we took appropriate steps to adjust our effect size estimate to offset the inflation caused by our small sample size, it is of course difficult to say with only one small sample whether our finding is a good estimate of the true population. In their review of educational gaming research, however, Qian and Clark (2016) found that over 60% of reported effect sizes in research on game-based learning were either moderate (17%) or large (46%), with moderate and large being defined as d = .5 and d = .8, respectively. It is not inconceivable, then, that our large effect size is an accurate estimate, and consequently that our small sample size does, indeed, have adequate power.

FUTURE DIRECTIONS

Aside from addressing the aforementioned issues related to sampling, we see several broad directions for extending our findings. Three of those directions, in particular, are experimental manipulation, statistical moderation, and assessment standardization. Although the present work leverages a relatively powerful repeated-measures design, it does not feature a true manipulation of the independent variable. That is, the specific content covered by the Minecraft modules did not receive any learning attempts without the use of the Minecraft game. Consequently, we are left with the confounding variable of the content itself. We have good reason to believe that the Minecraft related content in our study is not especially easy content to learn, relative to the non-Minecraft related content, yet it remains unclear to what extent the use of the game augmented the learning of that content in absolute terms (i.e., perhaps the students would have learned that content just as well without the game). Hence, future research featuring the manipulation of which tools are used to best learn one specific set of content would be valuable.

Another valuable future direction for this work is examining moderating variables, or variables that allow researchers to discern if there are varying degrees of effectiveness of an intervention for different groups of people. For example, it could be the case that the use of Minecraft or other simulations in engineering courses is particularly effective for students with more computer gaming experience, or students with weaker backgrounds in engineering. Upon determining if a particular strategy is generally effective, which we do by examining the overall average, one of the next important questions to ask is, “for whom is this strategy effective?”, or, “is this effect the same for everybody?”. Future work could begin to address these questions by theorizing about the possible mechanisms at work that contribute to enhanced learning from games like Minecraft and considering how those mechanisms might interact with certain individual differences among students.

Finally, it would be valuable for future research in this area to try and incorporate elements of standardization when it comes to measuring learning. This could be in the form of the development and use of concept inventories, for instance, or it could be through collaboration in the establishment of certain learning objectives across the various sub-disciplines that fall under the umbrella of college level engineering courses. We have provided a sample of the instruments we used to assess learning outcomes in this study (i.e., exam questions) with the hope that other engineering faculty will get a better sense of what the students were learning, although we admit it is highly unlikely that those faculty have or will ever use that same instrument in their courses. That is not to say that any variability among instruments is inherently problematic. Rather it is that, as more data becomes available, the emphasis on the question of whether learning outcomes are being measured is likely to shift more towards *how* they are being measured, and taking those details into consideration will continue to advance our collective understanding of how we can best meet the needs of our students.

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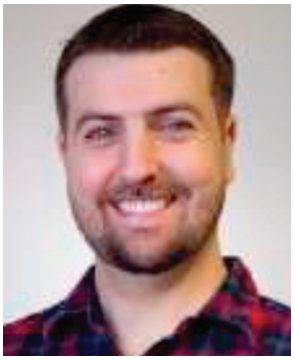
YOUTUBE CHANNELS WITH INSTRUCTIONAL VIDEOS

https://www.youtube.com/channel/UC_b6DDeKKDyT-I4SDDrVJVA/featured

https://www.youtube.com/@CMUMME/videos

Additional data and videos that support the findings of this study are available from the corresponding author upon request.

AUTHORS



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