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A Pretest-Posttest Quasi-Experimental Study for a Game Intervention in an Undergraduate Wireless Communications Course

Mr. Joshua Alexéi García Sheridan, Virginia Tech

Joshua García Sheridan is a PhD student in the Department of Engineering Education at Virginia Tech. He received his Bachelor's of Science in Electrical Engineering at the University of Illinois at Urbana-Champaign. His current research work include gaming and game-like interventions in engineering education and designing interactive educational tutorials for radio engineering, with research interests in explicitly mapping childhood stages of cognitive development to engineering knowledge and skills for K-12 curricula.

Dr. Richard M. Goff, Virginia Tech Department of Engineering Education

Richard M. Goff is a former aircraft structural test engineer for the Navy, a Peace Corps Volunteer, and a computer entrepreneur. He holds a Ph.D. in Aerospace Engineering, and is currently an Associate Professor in the Department of Engineering Education at Virginia Tech. Richard has been teaching and engaging in research in multidisciplinary engineering design education for over twenty years. Dr. Goff is the recipient of several university teaching awards, outreach awards, and best paper awards. His passion is creating engaging learning environments by bringing useful research results and industry practices into the classroom as well as using design research results to inform engineering practice.

Dr. Carl B Dietrich P.E., Virginia Polytechnic Institute and State University

A licensed Professional Engineer in Virginia, Carl Dietrich earned a BS EE degree from Texas A&M University, and MS EE and PhD EE degrees from Virginia Tech. He has taught courses in software defined radio, communications systems, electronics, and electromagnetic fields. He has also taught short courses on software defined radio since 2007, covering fundamental concepts and enabling technologies in addition to the use of open source software to develop and run SDR applications. In addition, Dr. Dietrich has performed and directed research in the areas of cognitive radio, software defined radio (SDR), multi-antenna systems, and radio wave propagation, and has authored or co-authored more than 50 peer-reviewed journal and conference papers. He has worked at Virginia Tech, Bell Northern Research, and the Defense Information Systems Agency. He has served as chair of the Wireless Innovation Forum's Educational Special Interest Group, is a member of ASEE and Eta Kappa Nu, Senior Member of IEEE, and an Extra class amateur radio operator.

Dr. Vuk Marojevic, Virginia Polytechnic Institute and State University

Vuk Marojevic graduated from University of Hannover (MS), Germany, and Polytechnic University of Catalonia (PhD), Spain, both in electrical engineering. He joined Wireless@Virginia Tech in Summer 2013 as a Research Associate. His research interests are in software-defined radio technologies with application to 4G/5G cellular, UAV, and spectrum sharing, among others. Dr. Marojevic has been instructor of undergraduate and graduate level classes at the Polytechnic University of Catalonia, Spain, and Virginia Tech.

Dr. Nicholas F Polys, Virginia Polytechnic Institute and State University

Nicholas F. Polys is Director of Visual Computing with Virginia Tech Research Computing Group and Affiliate Research Professor in the Department of Computer Science. He has developed interactive 3D graphic content and systems since 1998. His research interests lie at the center of graphics and Human Computer Interaction: the intersection of visualization, virtual environments, and perception. After his undergraduate research in Cognitive Science at Vassar College (1996), he jumped into the networked information space of the WWW developing audio, visual, and 3D assets and software. His doctoral work at Virginia Tech (2006) examined perceptual cues and layout behaviors for Information-Rich Virtual Environments for desktop to immersive platforms.

He is a member of ACM, IEEE Computer Society, and the Web3D Consortium. He is a co-author of the international standard (ISO) Extensible 3D (X3D), elected Director and President of the Web3D Consortium, and Chair of the Web3D User Interface Working Group.

Prof. R. Michael Buehrer, Virginia Polytechnic Institute and State University

Dr. R. Michael Buehrer joined Virginia Tech from Bell Labs as an Assistant Professor with the Bradley Department of Electrical and Computer Engineering in 2001. He is currently a Professor of Electrical Engineering and is the director of Wireless @ Virginia Tech, a comprehensive research group focusing on wireless communications. During 2009 Dr. Buehrer was a visiting researcher at the Laboratory for Telecommunication Sciences (LTS) a federal research lab which focuses on telecommunication challenges for national defense. While at LTS, his research focus was in the area of cognitive radio with a particular emphasis on statistical learning techniques.

His current research interests include geolocation, position location networks, iterative receiver design, dynamic spectrum sharing, cognitive radio, communication theory, Multiple Input Multiple Output (MIMO) communications, intelligent antenna techniques, Ultra Wideband, spread spectrum, interference avoidance, and propagation modeling. His work has been funded by the National Science Foundation, the Defense Advanced Research Projects Agency, Office of Naval Research, and several industrial sponsors.

Dr. Buehrer has authored or co-authored over 50 journal and approximately 125 conference papers and holds 11 patents in the area of wireless communications. In 2010 he was co-recipient of the Fred W. Ellersick MILCOM Award for the best paper in the unclassified technical program. He is currently a Senior Member of IEEE, and an Associate Editor for IEEE Transactions on Communications and IEEE Wireless Communications Letters. He was formerly an associate editor for IEEE Transactions on Vehicular Technologies, IEEE Transactions on Wireless Communications, IEEE Transactions on Signal Processing, and IEEE Transactions on Education. In 2003 he was named Outstanding New Assistant Professor by the Virginia Tech College of Engineering and in 2014 Dr. Buehrer won the Virginia Tech College of Engineering Award for Teaching Excellence.

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Abstract

The importance of preparing the next-generation workforce in engineering cannot be overstated. Undergraduate engineering education is vitally important to this venture and must undergo continuous improvements to meet dynamically changing needs in industry research and development. Of the many areas of engineering that benefit from pedagogical innovations, this study focuses on the context of teaching wireless communications.

Wireless communications is a dynamic field, responsible for advances in cellular, Wi-Fi, Bluetooth, and other technologies and systems using the wireless medium for communications. Engineers recruited by industry are expected to design new and innovative systems for wireless technologies as the field continues to expand in its applications, which include mobile devices, peripherals, and networks. This constantly changing and evolving industry in wireless communications requires undergraduate engineering students to learn more advanced engineering concepts. We argue that sophisticated principles can be effectively introduced at the undergraduate level. Current state-of-the-art technologies normally taught to graduate students are now being explored in undergraduate education, and novel methods of instruction are necessary to provide a scaffold for advanced learning at the undergraduate level.

To enhance learning as interactive decisional aids, serious games in education are proposed to better educate, motivate, and engage students. Games may also be used to acquaint students with machine thought in a robust manner. In this research, a game exploring wireless communication concepts is created. A quasi-experimental study is then performed to determine the effects of an intervention of access to a wireless communication concepts and interactive quiz game on student performance using numerically scored quizzes. This was implemented in a wireless communications course of 30 students in an undergraduate engineering program. Nonparametric comparative analyses are performed to determine the effect of the game intervention so as to answer the following research question: What is the change in student performances in an undergraduate communications course that uses a game intervention to deepen understanding of wireless topics in the course material?

Introduction

The importance of preparing the next-generation workforce in engineering cannot be understated. Undergraduate engineering education is vitally important to this venture and must undergo continuous improvements to meet dynamically changing needs in industry and research.

This paper explores the effects of a pedagogical intervention in an undergraduate course in wireless communications intended to improve student learning.

Higher levels of education in wireless communications will promote increased engagement with current research advances, better preparing students for jobs, and motivating the pursuit of graduate degrees. The challenge in this respect is teaching students more advanced material and skills in preparation for a more advanced curriculum. This is a task of huge complexity with regards to time, resources, funding, and provision of the appropriate learning environments to incorporate more advanced topics into the curriculum in the program. As a result, accessibility of a complex subject requires managing pedagogy that motivates learning and engages students. Below is a brief description of the advancements within the engineering field that generates the impetus for accommodating such a curriculum shift and how the approach studied shall address it.

Wireless Communications Advancements

Wireless communications is a dynamic field, responsible for advancements in Wi-Fi, radio, Bluetooth, etc. Engineers recruited to industry are expected to design new and innovative systems for wireless technologies as the field continues to expand in its applications, which include mobile devices, peripherals, and networks. Continued advancement of wireless communications requires knowledge of engineering principles currently taught to only graduate students in courses such as ECE 4634 at Virginia Tech. Demands of the industry are persuading universities to make this knowledge more accessible to engineering students. If we intend today's students to develop tomorrow's systems, they must be educated beyond current departmental standards in wireless communications. Teaching wireless communication at an undergraduate level must meet the pace and demands of the field.

Important changes in wireless communications happen every few decades (Jondral, 2008). However, technology evolves at an increasing pace and communications systems are continuously upgraded within a standards framework. For example, the 4^{th} generation long-term evolution (LTE) is omnipresent today, but it has many flavors. New features are frequently introduced and new releases of the standard are completed approximately every 18 months. LTE Release 8 was published in 2008; Release 14 is underway at the time of writing. Among the next-generation material that should be considered for wireless communications education is cognitive radio technology and dynamic spectrum access, which is already part of the 4G LTE framework through LTE-Unlicensed and the 3.5 GHz band in the United States (Sohoul, 2016) and will most likely become a key concept of next generation 5G systems. These curricular additions can make an electrical engineering department's wireless classes more compatible to industry employers' and graduate schools' needs.

Restricted radio frequency (RF) bands that have been licensed have created inefficiencies because of high use at peak hours (insufficiency capacity) and low use at other times (inefficient use of RF spectrum). As a result, many bands end up being crowded while other unused bands that could be used instead are barren. More flexible regulation of RF access that does not cause harmful interference can resolve this. In fact, such technology has been conceived such as cognitive radios (CR) (Mitola & Maguire, 1999) and dynamic spectrum access (DSA) (Noam, 1995) capable of achieving more flexibility in how wireless networks function. Cognitive radios can determine if other radios use the same bands and move into an unoccupied portion of the spectrum such that they do not interfere with one another. Additionally, they do so automatically without need for human intervention.

Games and Gamification in Education

One of the major hurdles to overcome in the education process is teaching the computational processes involved in CR and DSA technologies. A startling disparity exists between how machines are made to function and how humans reason (Kahneman & Tversky, 1979). Studies show that humans perform terribly at a consistent rate on reasoning tasks in computational logic.

A scaffold is necessary. One author who has studied the cognitive discrepancies concludes that biases in reasoning may be identified and mitigated through interactive decision aids (Evans, 2003; Evans, 2009). Games can provide an interactive decision making environment to accomplish this. Games reinforce rational reasoning using gameplay experiences as a medium for education. Hamari, Koivisto, and Sarsa (2014) have suggested that what people learn in games "can be used by teachers to enhance their teaching and better prepare students for technology-based society" (Keramidas, 2010). Serious games can be designed to motivate and engage users (Gee, 2003) to master class material, demonstrated by their performance on quizzes and tests. Serious games are capable of doing this through characteristics that can challenge players with constraints through rules (Dörner, Göbel, Effelsberg, & Wiemeyer, 2016). When finely tuned, the rules of a game set the player at performing just above their perceived level of skill in a challenge, and they remain in a state of flow (Csikszentmihalyi, 1990), feeling rewarded for continuing to play and continuing to the next challenge. Other prominent theories related to pedagogy, cognition, and learning similarly apply to serious game design principles of immediate feedback, interactivity, challenge, competition, and other appeal mechanisms that compose a game (Dörner et al., 2016), including Self Determination Theory (Deci & Ryan, 2002) and Merrill's *model for successful learning* (Merrill, 2002).

Through the experiential process and cognitive augmentations to increase motivation and engagement provided by these interactive experiences, students can be guided by games to adopt logical reasoning and prepare them for working with CR and DSA technologies. It is therefore a worthy prospect to perform an initial investigation of whether or not the most visible expected effect of these serious games, i.e. student performance improvements, will be observed when such games are administered in an undergraduate communications class.

Purpose of the Study

This quasi-experimental study's purpose is to determine if using serious games as reinforcement material for an undergraduate communications class enhances learning such that student performance in an online assessment structure improves. As part of a larger research grant, it serves as a small-scale pilot study to determine if any immediate improvements in content mastery are achieved. Based on improvements in student performance using games in other subjects (Hamari, Koivisto, and Sarsa 2014), it is hypothesized that there will be significant positive changes to student performance. The study attempts answering the following research question: What is the change in student performance in a communications course that uses a game intervention to deepen understanding of the course material?

Methods

Sampling

Students in ECE 4634 at Virginia Tech were asked to participate in the study for extra credit, provided that certain directions were followed. Assuming all students are interested in extra credit, the sample should not be biased towards certain students, but the possibility exists that unmotivated students would not participate with such an offering either from the standpoint of being confident in their grade or not feeling that the extra credit would make a difference. This is a non-random sample, as the class was composed of only 31 students and all were offered participation through an IRB approved recruitment and online informed consent process. Thirty students consented for their results data to be published in this study. The students in the sample were not instructed by one of the researchers.

Game Intervention

The game can be described as an interactive software application that connects with Virginia Tech's programmable radio network system, CORNET (Cognitive Radio Network Testbed), which uses real radios that can communicate with one another as well as serve in roles of interference. CORNET's online interface features a GUI that displays vital radio communication information such as power, RF frequencies and bandwidth, as well as modulation and other signal generation and spectrum shaping parameters with a wide variety of available options.

The game generally requires the student to design a radio configuration (modulation scheme and transmit power) given BER, link distance, and/or bandwidth constraints. The game has four levels that students can play through, and students were told to play each level until the optimal solution is obtained, to receive the extra credit. At each level, the game gets harder through the addition of constraints within the requirements of design. Students' attempts are recorded and players receive more points for fewer tries to complete each level. Hints are also available at a price of one attempt. As stated to the students, the game was designed with the goal of helping the students gain intuition about the relationships between bandwidth, power, modulation scheme and performance.

Procedure Background

This quasi-experimental procedure follows a pretest-posttest design with switching replications. Due to fairness issues in the course, a control group of students in the class could not be secured without them knowing that other students were allowed to participate. This adapted method is strong because of its ability to measure performances between two groups or more by cascading the point when they are given treatments. It allows both groups to receive the treatment by the end of the study. It has limitations in not being able to remove treatments from treatment groups, but in the case of this study, we are not concerned with this because the first quiz scores may be used as control data, enabling sample groups to act as controls for each other (Shadish, Cook, & Campbell, 2002).

Administration

To obtain extra credit, students were asked to participate in a quiz on class material, followed by playing the game a number of times once it was made available to them, then participate in a second quiz. The game had different variables each time it was played. Thirty students agreed to participate in the game intervention, so they were divided into two groups of 15, A and B. Group A would serve as the treated sample with Group B acting as a control group for the first two quizzes. Group B would then receive the game and constitute another usable sample for the intervention.

This structure allowed for fairness despite having a group acting as a control; the game was ultimately delivered to all participating students to benefit them. Both groups were delivered each of the successive quizzes as scheduled. No material contributing to topics covered in the quizzes was presented during this timeframe. The timeframes of game intervention and quiz distribution are displayed in Table 1 below:

Table 1: Timespan of quizzes and intervention

Day	1	2	4	4	6
Event	Quiz 1 conducted	Group A received game	Quiz 2 conducted	Group B received game	Quiz 3 conducted

Quizzes

Each quiz was scored out of 10 points for 10 multiple-choice questions drawing from course content. These quizzes were conducted online and no quantitative feedback was given to students after administration until after the all three quizzes had been issued, meaning they were not given any indication of whether they got questions right or wrong before all quizzes were complete.

In addition to changes in number values of parameters, the quiz questions were not always asked in the same format, nor did they have the same pool of answers for similar questions. The variation ensures validity in that students could not simply study for the same exact question from what had been seen before and mark the correct answer. The implications of this variation with regards to the results found will be discussed in greater detail later.

Data Gathering and Analysis

The instructor of the course delivered the instructions, gave student access to the game at appropriate times, and conducted the quizzes online and consolidated the class's individual scores of each quiz. The scores were anonymized in accordance with IRB protocols and input with coded designations (e.g. A1, B12, etc.) for each student. The data were imported into SPSS for analysis.

The sample consisted of 15 students in Group A and 15 students in Group B. Quiz scores were separated by group for analysis (Quiz 1 for Group A, Quiz 1 for Group B, etc.).

Results & Analysis

Through statistical analysis, the study aims to determine the following:

(1) Is there a statistically significant difference between quiz scores before and after receiving the game intervention?

(2) Does the game intervention explain the difference?

The null hypothesis for (1) would be that there is no statistically significant difference between scores, while the alternative hypothesis would be that there is. An affirmative answer to (2) would support the assertion that the game intervention had a positive effect on student performance.

Due to inconsistent participation by students, the number of students in each group that took a particular pair of quizzes varied. As can be seen in the descriptive statistics in Table 2, the greatest number of students in a group that took a quiz together was Group A when taking Quiz 1. In all other cases, significant numbers of students were absent, and students did not consistently participate in each quiz, further affecting the sample sizes available for statistical tests. Quiz differences are also presented to add additional clarity to what the data show for the analyses that follow.

Table 2. Descriptive statistics for quiz scores

	N	Mean	Std. Deviation	Minimum	Maximum
Quiz 1 for Group A	14	5.0714	2.12908	2.00	10.00
Quiz 1 for Group B	10	5.9000	1.91195	3.00	9.00
Quiz 2 for Group A	9	7.1111	2.36878	2.00	10.00
Quiz 2 for Group B	9	6.8889	1.76383	3.00	9.00
Quiz 3 for Group A	8	5.7500	2.25198	3.00	9.00
Quiz 3 for Group B	11	5.5455	2.76997	1.00	10.00
Quiz 2 – Quiz 1 (Both Groups)	15	2.0667	1.57963	-1.00	5.00
Quiz 3 – Quiz 1 (Both Groups)	16	0.1875	2.34432	-4.00	5.00
Quiz 2 – 1 (Group A)	8	2.2500	1.48805	-1.00	4.00
Quiz 2 – 1 (Group B)	7	1.8571	1.77281	0.00	5.00
Quiz 3 – 1 (Group A)	7	0.7143	2.36039	-2.00	4.00
Quiz 3 – 1 (Group B)	9	-0.2222	2.38630	-4.00	5.00

Normal distributions are not expected for small sample sizes such as this, so nonparametric tests were conducted to perform comparisons of performances between groups A and B. To start, a Mann-Whitney Test was conducted for each quiz score, comparing the performance of Group A to Group B. The results are depicted in Table 3.

Table 3. Mann-Whitney tests for individual quiz scores

	N	Mann-Whitney U	Exact Sig. (2-tailed)	Mean Rank (Group A)	Mean Rank (Group B)
Quiz 1	24	52.000	0.300	11.21	14.30
Quiz 2	18	36.500	0.753	9.94	9.06
Quiz 3	19	42.000	0.891	10.25	9.82

For each particular quiz, none of the quiz scores between the groups are significantly different from one another for $p < 0.05$. While this is to be expected for Quizzes 1 and 3, Quiz 2 would have been the important point for differences to be observed, being that it is the quiz where one group had not received the intervention while the other had.

When considering improvements in performances, a similar observation occurs, as shown in Table 4. For the purposes of this study, the major considered points were the performance differences between Quizzes 1 and 2 (a comparison of a test group and a control group) and those of Quizzes 1 and 3 (two groups that both received the intervention in between the considered quizzes). As may be expected, no significant differences between the two groups were observed for the changes in performance between Quizzes 1 and 3. However, the same applied to the groups' performance changes between Quizzes 1 and 2.

Table 4. Mann-Whitney tests for differential quiz scores

	N	Mann-Whitney U	Exact Sig. (2-tailed)	Mean Rank (Group A)	Mean Rank (Group B)
Quiz 2 – Quiz 1	15	21.500	0.465	8.81	7.07
Quiz 3 – Quiz 1	16	25.000	0.501	9.43	7.78

Finally, a Wilcoxon Signed Ranks Test was performed for the entire applicable set of students (N = 16) from both groups that participated in both Quizzes 1 and 3 to determine if any significant change had been observed in general for performance after the intervention. In this case, shown in Table 5, the participating samples in each quiz were considered related. The analysis was performed with consideration to the difference of Quiz 1 minus Quiz 3, meaning that positive ranks consider the cases where Quiz 1 scores were greater than those of Quiz 3. Negative ranks consider cases where Quiz 3 scores were greater than Quiz 1 scores. Exact significance shows that the level of difference was entirely expected within a Wilcoxon method. This was repeated for Table 6, but with Quizzes 1 and 2 (N = 15). Note how this test shows that there are significant differences being observed by the sample in general for Quiz 2 and Quiz 1.

Table 5. Wilcoxon Signed Ranks test for "Quiz 1 – Quiz 3" (all applicable students)

	N (Positive Ranks)	N (Negative Ranks)	N (Ties)	Z (Based on negative ranks)	Exact Sig. (2-tailed)
Value	7	4	5	-0.045	1.000
Mean Rank	8.13	4.79			
Sum of Ranks	33.50	32.50			

Table 6. Wilcoxon Signed Ranks test for "Quiz 1 – Quiz 2" (all applicable students)

	N (Positive Ranks)	N (Negative Ranks)	N (Ties)	Z (Based on positive ranks)	Exact Sig. (2-tailed)
Value	1	12	2	-3.104	0.001
Mean Rank	1.50	7.46			
Sum of Ranks	1.50	89.50			

Considering these comparative analyses, it would appear that no statistically observable differences exist between the two participating groups of students with consideration to either performances on quizzes or improvements therein. As such, a statistical determination may not be made about the effect of the game intervention upon student performances.

Discussion

Students for some reason other than the game intervention have noticeably higher scores in the second quiz. As statistically established, the difference in scores cannot be explained by the game intervention because the magnitude of these differences between game participants and the control group was not significantly different. For Quizzes 1 and 2, Group A was treated with a game intervention while Group B acted as a control group and was not given access to the game, yet their scores were neither significantly different from each other nor significantly different in how they changed. The analysis provided does not support the idea that the game intervention was the reason for increases observed, though the increases observed were most certainly significant themselves as shown by the Wilcoxon Signed Ranks test. As stated before, the quizzes were structured similarly to one another, but did not necessarily cover exactly the same problem topics or types in each of the three iterations. It is therefore possible that concepts more effectively learned in the classroom were more salient in Quiz 2 than either of the other two quizzes.

Additionally, the Wilcoxon test decisively shows that the quiz performance differences for students that received the intervention did not approach a point that was significant for Quizzes 1 and 3, and there were several more cases where students did worse overall than better on the Quiz 3. This is also reflected in the general means for quiz differences between Quizzes 1 and 3, which are similar in general as they are for each particular group. This may mean that students did not improve in their understanding such that their quiz scores could have improved as a result of the game. On the other hand, it may mean that Quiz 3 was also harder to perform at the same level as Quiz 1, and students were simply able to maintain the value of their scores overall as a result.

Unfortunately, the statistical analyses regarding quiz scores show a lack of conclusive evidence to suggest that the game intervention had any significant effect on student performance. It must be considered, however, that students had not been trained with the software for this game previously and that, given the short time frame and small sample size, the experimental procedure does not necessarily reflect either the implementation of games in the classroom or effect it has on student performance. The incorporation of the game-based instruction format throughout a semester may have a more significant and observable effect if measured appropriately. A longitudinal study of the course and its outcomes of student performance could be a more appropriate direction to take in assessing the game instrument's effectiveness as a learning tool.

Limitations

The study is limited by a variety of factors that arose from circumstances as well as procedural conduct. Principally, the sample size is too small to make any sweeping generalizations with regards to the data obtained. Given the small class size available for the course, this may not change over time from one school year to the next, but a congregation of data from multiple years of conducting experiments of this sort would prove beneficial for strengthening the generalizability of the data.

It is unknown in what way it affects the results in this study, but students were asked to perform during the period of the intervention via handout. In the handout, the request to play the game and the number of extra credit points associated with it had bolded text. A necessary additional task the students had to complete to receive extra credit, however, was to take all three quizzes. This sentence did not use bolded text. (This was an oversite in the presentation of the instructions.) The overall intention was to ensure that all students participated in each quiz to yield a full data set for analysis. As it happened, only 20 students out of 30 took a quiz before and after the intervention. Some of those students did not take all three quizzes. Clarity of the communication to the subjects in this study may have affected results that would have otherwise been obtained. This will be corrected in future studies.

Finally, the discrepancy in quiz scores between Quiz 2 and the others has already been mentioned. This weakens a claim of reliability in equivalent forms for the quizzes such that the quizzes are not similar enough that students can reliably obtain the same scores. This constitutes a severe limitation for the study. It may be that some changes that were made to Quiz 2 in comparison to the other two quizzes could be associated with the increased scores, but there was no data collected on each question response for this study. The tracking of individual answers may constitute a prudent modification for future iterations of this study so that deeper understanding of patterns in performance may inform conclusions about the game intervention from experimental results. For example, a piloted set of standard quizzes that could be assessed to cover identical competencies (not merely similar ones) may provide a more reliable measurement tool of students' understanding of course material.

Conclusions

In this study, we used a pretest-posttest quasi-experimental method with switching replications to determine whether or not a game intervention in a wireless communications class would improve student performance. Conducting analyses of quiz scores, score differences between students' first and last quizzes, and interrelations between two groups of students that received the intervention at different times, we draw no significant conclusions about how student performance is affected by the game intervention. Further research will seek to improve quiz design and create clear instructions. Ideally, we can monitor changes in student performance in long-term circumstances and through several years of sampling to improve generalizability of the study and come to more useful conclusions regarding the pedagogical application of the game instrument. Also note that the specific game that was introduced in this example may not cover all the necessary features of serious games to make broad conclusions. In the future, we will analyze this and its effect on the outcomes.

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