Computer Game-based Pedagogy: An Experimental Investigation

Clement Yeboah [1], Thomas Lipscomb [2]

[1] School of Education, [2] Ph.D., Educational Research,
University of Southern Mississippi,
United States of America.

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Abstract

A pre-test-post-test within subjects, experimental design was employed to examine the effects of a computerized basic statistics learning game on achievement and statistics-related anxiety of students enrolled in introductory graduate statistics course. Participants (N = 12) were graduate students in a variety of programs at state-funded research university in the Southeast United States. We analyzed pre-test-post-test differences using paired samples *t-tests* for achievement and for statistics anxiety. The results of the *t-test* for knowledge in statistics were found to be statistically significant indicating significant mean gains for statistical knowledge as a function of the game-based intervention. Likewise, the results of the *t-test* for statistics-related anxiety were also statistically significant indicating a decrease in anxiety from pre-test to post-test. The implications of the present study are significant for both teachers and students. For teachers, using computer games developed by the researchers can help to create a more dynamic and engaging classroom environment, as well as improve student learning outcomes. For students, playing these educational games can help to develop important skills such as problem solving, critical thinking, and collaboration. Students can develop interest in the subject matter and spend quality time to learn the course as they play the game without knowing that they are even learning the presupposed hard course. The future directions of the present study are promising, as technology continues to advance and become more widely available. Some potential future developments include the integration of virtual and augmented reality into educational games, the use of machine learning and artificial intelligence to create personalized learning experiences, and the development of new and innovative game-based assessment tools.

Keywords: Computer Game-based Learning, Statistics Achievement, Statistics Anxiety

Active learning is well known to be important to the learning process and the key to active learning is engagement on the part of the student. In this vein, computer game-centered learning has garnered much attention in academic environments during the last 25 years as a means of fostering a high degree of student engagement (McLaren et al., 2017; Stiller & Schworm, 2019). A video or computer game is generally any game played using a computer or other digital device with a video display. The device may be a cell phone, a game console, desk-top or lap-top computer, etc. (Adams et al., 2012; Paolini, 2015; Ronimus et al., 2019) but such a definition is insufficient to capture the complexity and diversity of the medium (Adams et al., 2012; Laird et al., 2014; Paolini, 2015; Ronimus et al., 2019). Although

Akçapinar (2015) noted, to engage a player in such a game some elements of conflict is often introduced that is well explained and defined, and that requires the players' intervention. The plot of the game and the background of the narrative are based on such conflicts and define the goals and objectives that the players must achieve in order to finish or complete a specific task within the game. To achieve the proposed objectives or goals of the game, the player(s) must operate in accordance with the specified rules of the game, which define or describe what can and cannot and be done within the context of the game (All et al., 2014; Anderson & Barnett, 2011).

Some scholars have posited that computer-based learning games have the capacity to enhance various aspects of motivational, behavioral, cognitive, affective, and perceptual outcomes (Connolly et al., 2012; Li & Tsai, 2013; Tobias et al., 2014; Paolini, 2015; Boyle et al., 2016; Clark et al., 2016; Merino Campos & del Castillo Fernández, 2016; Parong et al., 2017). In their extensive review of the literature, Connolly et al. (2012) considered a total of 129 published studies concerning the use of computer game-based interventions in a variety of disciplines and for a variety of learning-related outcomes. Some of these studies were descriptive or correlational in design while a few employed designs permitting a degree of causal inference such as quasi-experimental and regression discontinuity designs. The authors point out that overall, there is a lack of empirical evidence concerning the efficacy of such experimental designs to clearly delineate cause and effect relationships (Connolly et al., 2012). Neither is their empirical evidence that game-based interventions can be effective in fostering content mastery in the area of statistics nor is there any evidence that such can be effective in reducing statistics-related anxiety.

This is unfortunate as mastery of statistics is central to success in a variety of fields including education, business disciplines, and the behavioral sciences more broadly. Statistics instruction has been a particularly problematic area presenting as it presents relatively unique challenges to both students and instructors in terms of instructional design and delivery. One of the major impediments to successful mastery of statistical concepts and computational methods is known to be anxiety associated with the learning of statistics (Edirisooriya & Lipscomb, 2021). In fact, the experience of anxiety constitutes a major impediment to learning in a variety of content domains including mathematics (Galla & Wood, 2012; Lorenzen & Lipscomb, 2021, Lipscomb & Lorenzen, 2023, Luttenberger et al., 2018; Paechter et al., 2017). In general, anxiety is experienced as a negative emotional state that is described as being associated with such difficulties as excessive worry and apprehension. Of particular relevance to present considerations is the fact that the experience of anxiety makes it very difficult to deploy and sustain attention, which are requirements for statistics mastery (Brandish & Baldwin, 2012; Jehu, 1970) and is known to be typically associated with low self-appraisal of one's own abilities (Brandish & Baldwin, 2012). Further, there is evidence that the experience of statistics-related anxiety is quite common among post-secondary students required to take such courses (Baloğlu et al., 2011; Onwuegbuzie & Wilson, 2003). As Chew and Dillon (2014) describe it, anxiety towards statistics consists of:

> …a negative state of emotional arousal experienced by individuals as a result of encountering statistics in any form and at any level; this emotional state is preceded by negative attitudes toward statistics and is related to but distinct from mathematics anxiety. (p. 199)

In addition, at the graduate level at least, there is evidence for both gender and age-related differences in the experience of statistics-related anxiety with women and older students reporting experiencing anxiety to a greater extent than do men and younger students (Edirisooriya & Lipscomb, 2021). As such, this could represent a barrier to academic success and entry into the STEM professions in particular as in which statistical knowledge is vital for both women and older persons.

Employing an experimental design, the present study had as its purpose examining the potential effects of computer game-based learning on the possible reduction of statistics-related anxiety and enhancement of statistics content mastery among graduate students. The game that served as the intervention was developed specifically for the purposes of the present study. The study took place at a medium-sized comprehensive university in the southeast United States. The researchers posed the following research questions: First, what effect if any, does computer game-based learning have on students' level of statistics anxiety? Second, what potential effect does computer game-based learning have on students' statistics content mastery?

Visual Basic for Application (VBA) was used to develop the intervention game. There is a built-in data generator in the CYNTL computer game-based learning program that the researcher has developed which served as the intervention in the study. A VBA is a programming language within Excel which is embedded within an individual Microsoft application in which a programmer can automate several tasks, referred to as "MACROs " (Hassan, 2022). In the present case, the CYNTL computer game was built based on the content of the course syllabus for the course in which the participants were enrolled. In addition. A "filler" game unrelated to course content was used in the control (non-intervention) condition.

Method

Sample

Students enrolled in an introductory graduate statistics course delivered in an online format at state-funded research university in the Southeast United States of America participated in the study. Out of the total number of the 14 graduate students enrolled in the course, 12 participated (3 males, representing 25% and nine females representing 75% of the sample respectively) in the computer game intervention (CYNTL). Approximately 25% of the participants were pursuing a Ph.D. in Research Evaluation Statistics and Assessment, 33% pursuing either an Ed.D., 17% in Ph. D. in Communication, and 25% did not specify their major. Approximately 42% of the participants identified a White Americans, 25% as African Americans, 8% as Asian, 8% as Hispanics, and 17% did not specify their ethnicity.

Research Design and Instrumentation

This study employed a pre-test-post-test, between groups experimental design to examine the causal effects of computer game-based learning on statistics content mastery and statistics-related anxiety among the graduate students. Each participant played both the game-based intervention (statistics related computer game) and the "filler" game (a non-statistics-related computer game) but the timing differed for the experimental and control groups to allow causal comparison of the effects of playing the game on statistics-related anxiety and content mastery as well as to give all students the opportunity to experience the intervention for ethical reasons. The design is expressed as follows where: O^1 = pre-tests, X = intervention (game), O^2 = post-tests.

Experimental Group:	O^1	X	O^2	
Control Group:	O^1		O^2	X

The dependent variables in the study were statistics content mastery and statistics-related anxiety. The Statistics Anxiety Rating Scale (STARS) developed by Cruise et al. (1985), was used with permission for the pre-test and post-test measures of statistical anxiety. The STARS assesses six dimensions of statistics-related anxiety: Worth of Statistics, Interpretation Anxiety, Test and Class Anxiety, Computational Self-concept, Fear of Asking for Help, and Fear of Statistics Teachers.

In addition, the researchers developed a set of items based upon participants' course syllabus to measure statistical content mastery and to ensure content validity of the latter measure.

Maat et al. (2017) provided evidence for the construct validity of the STARS reporting that six factors with loadings ranging from 0.68 to 0.80. Maat et al. reported an overall Cronbach alpha of .96, indicating a high level of internal consistency reliability.

Procedure

The study was conducted online. After receiving permission from the class instructor and the University's Institutional Review Board, the experimenter met with the class via Zoom to give a brief introduction of the game, and the purpose of the study. He demonstrated the procedure for the game and assured the participants that their participation was completely voluntary, and that all data would be anonymous as specified in the informed consent document. Students who volunteered to participate were asked to click a hyperlink in a zoom chat menu that directed them to the Qualtrics hosting site where they first encountered the informed consent letter that explained the nature and purpose of the study and provided additional information concerning participation. Additional information concerning the games was provided to those who agreed to continue. All participants were randomly assigned to either the experimental or control conditions. Before playing the games, all participants completed and submitted via the Qualtrics the STARS and the statistics content mastery instrument developed for the purpose of the study which served as the pre-test measures. After the participants had completed the pre-tests for both statistics-related anxiety and content mastery, the experimenter provided them with links to the Zoom platform that directed each individual to the assigned game (intervention or filler). Accordingly, they were assigned to one of two different breakout rooms based on experimental condition. In each group breakout room, the experimenter explained the rules and procedures for the games according to condition. Both groups had approximately the same time length (30-45) minutes to play their respective games via Zoom. The experimenter requested each participant to turn their video/webcam on. The experimenter visited breakout rooms to monitor the proceedings. While one group was in the intervention game breakout room, the other group was in the filler game breakout room. Once the games were over, participants stayed logged into the meeting and were debriefed about their experiences while he took notes. Participants were then directed to the post-tests in Qualtrics. The CYNTL computer game-based learning has a built-in data saver that is retrievable by only the experimenter.

Results

Difference scores from pre-test to post-test were computed for results of the STARS. These differences were analyzed by means of a paired samples *t* test. Cronbach's alpha was conducted to check the internal consistency reliability of STARS for the present study. The alpha value for the five-item statistics content mastery rating scale was .778 (see Table 5), and that for the STARS was .678 (see Table 6), indicating sufficient homogeneity among items, further evidence for construct validity. The results of a paired *t*-test for statistics content mastery test pre-test – post-test differences indicated a statistically significant increase in scores for the experimental, t (11) = 6.89, p = .001, d = 1. 99, but not the control group, t (11) = .551, p = .593d = .16. The results of a paired *t*-test for the statistics anxiety measure test for treatment group pre-test - post-test difference indicated a statistically significant decrease in scores for the experimental, t (11) = 1.63, p = .032, d = .47, but not for the control group, t (11) = 5.531, p = .001, d = 1. 54, (see Table 6).

Discussion

Computer game-centered learning has garnered much attention in academic environments over the course of the last 25 years as a means of fostering a high degree of student engagement with the material to be mastered. Even though previous studies have demonstrated that computer games can have significant positive effects on students' academic success in a variety of content areas (e.g., Akçapinar, 2015; All et al., 2014; Boyle et al., 2016; Paolini, 2015; Ronimus et al., 2019), no study had previously investigated the possibility of a direct causal link of computer game-based pedagogy to either graduate students' statistics content mastery or statistics anxiety. In order to investigate for possible effects, this study employed a pre-test-post-test, between groups, experimental design to examine the potential effects of a computerized statistics learning game on content mastery and statistics-related anxiety of students enrolled in introductory graduate statistics course. This design is quite high in internal validity, eliminating all major threats to causal inference (Cambell & Stanley, 1963; Grabbe, 2015; Imai et al., 2013; Shadish et al., 2002). Participants in this study were graduate students representing a variety of programs at mid-sized, state-funded research university in the Southeast United States. The results of the present study clearly demonstrate the efficacy of a game-based intervention in increasing content mastery of statistics while reducing statistics-related anxiety. Specifically, as compared to a non-intervention control group, following engagement with the instructional game, the measure of content mastery increased to a statistically significant extent from pre-test to post-test, while the measure of statistics anxiety decreased to a significant degree. The current results have important practical implications. First, they demonstrate the potential efficacy of a computer game-based intervention in enhancing graduate students' learning outcomes while at the same time reducing the statistics-related anxiety that students commonly experience in statistics courses, success in which is vital in a variety of fields including STEM fields. Both effects, increased content mastery and anxiety reduction, are therefore important and very likely intertwined. Further, since it is documented in the literature that women and older individuals frequently experience an exceptionally high level of statistics anxiety and often struggle in statistics courses (Edirisooriya & Lipscomb, 2021), the present results hold the promise of being effective in removing barriers for women and older persons to enter into and be successful in professional disciplines requiring facility with statistics including STEM fields.

Limitations

The cost of developing and purchasing the present educational games software was high, making it difficult for the researchers with limited budgets to purchase high quality App Development Software such as Jira, Zoho, TrackVia, TestRail, SonarQube, etc. Also, some educational games such as CYNTL computer game-based learning developed by the researchers required high-end computers, internet connectivity, and other technical resources that were not available in all the homes of the participants. This made some of the participants/players experience some technical challenges when playing the intervention game. Again, some students were not motivated to play these present educational games, and some found the games too challenging or boring. This impacted their engagement and learning to affect the objective of the study and as a result, they stopped participating/playing.

Implication and Future Directions

The implications of the present study are significant for both teachers and students. For teachers, using computer games developed by the researchers can help to create a more dynamic and engaging classroom environment, as well as improve student learning outcomes. For students, playing these educational games can help to develop important skills such as problem solving, critical thinking, and collaboration. Students can develop interest in the subject matter and spend quality time to learn the course as they play the game without knowing that they are even learning the presupposed hard course. The future directions of the present study are promising, as technology continues to advance and become more widely available. Some potential future developments include the integration of virtual and augmented reality into educational games, the use of machine learning and artificial intelligence to create personalized learning experiences, and the development of new and innovative game-based assessment tools. It is also important to consider the ethical implications of computer game-based pedagogy, such as the potential for games to perpetuate harmful stereotypes and biases. As the field continues to evolve, it will be crucial to address these issues and work towards creating inclusive and equitable learning experiences for all students. This study has the potential to revolutionize the way basic statistics graduate students learn and offers exciting opportunities for future development and research. It is an important area of inquiry for educators, researchers, and policymakers, and will continue to be a dynamic and rapidly evolving field for years to come.

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Table 1: Mean Differences (Gains) and 95% Confidence Intervals of Pre- and Post-tests of the Statistics Content Mastery-Paired Samples Test

		Test value = 0					t	df	Sig. (2-tailed)
		Mean	Std. Deviation	Std. Error Mean	95% Confidence Interval of the Difference				
					Lower	Upper			
Pair 1	statistics content mastery test for treatment group pre-test - statistics content mastery test for control group pre-test	2.417	15.192	4.386	-7.236	12.069	.551	11	.593
Pair 2	statistics content mastery test for treatment group post-test - statistics content mastery test for control group post-test	13.333	6.706	1.936	9.073	17.594	6.888	11	.000

Table 2: Mean Differences (Gains) and 95% Confidence Intervals of Pre- and Post-tests of the Statistics Anxiety-Paired Samples Test (Mean Decrease)

		Test value = 0							
		Mean	Std. Deviation	Std. Error Mean	95% Confidence Interval of the Difference: Lower	Upper	t	df	Sig. (2-tailed)
Pair 1	statistics anxiety test for treatment group pre-test - statistics anxiety test for control group pre-test	13.917	9.010	2.601	-19.641	8.192	5.351	11	.000
Pair 2	statistics anxiety test for treatment group post-test - statistics anxiety test for control group post-test	6.000	12.792	3.693	-14.128	2.128	1.625	11	.032

Table 3: Mean Scores for Statistics Content Mastery

		Mean	N	Std. Deviation	Std. Error Mean
Pair 1	statistics content mastery test for treatment group pre-test	76.17	12	8.200	2.367
	statistics content mastery test for control group pre-test	73.75	12	10.830	3.126
Pair 2	statistics content mastery test for treatment group post-test	97.58	12	3.753	1.083
	statistics content mastery test for control group post-test	84.25	12	5.362	1.548

Table 4: Mean Scores for Statistics Anxiety

		Mean	N	Std. Deviation	Std. Error Mean
Pair 1	statistics anxiety test for treatment group pre-test	81.92	12	7.217	2.083
	statistics anxiety test for control group pre-test	95.83	12	4.041	1.167
Pair 2	statistics anxiety test1 for treatment group post-test	71.83	12	9.618	2.777
	statistics anxiety test1 for control group post-test	77.83	12	9.953	2.873

Table 5: Reliability Statistics for Statistics Content Mastery

Cronbach's Alpha[a]	Cronbach's Alpha Based on Standardized Items[a]	N of Items
.778	.785	5

Table 6: Reliability Statistics for Statistics Anxiety

Cronbach's Alpha[a]	Cronbach's Alpha Based on Standardized Items[a]	N of Items
.678	.714	5