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Comparison of Game-based Learning and Traditional Lecture Approaches to Improve Student Engagement and Knowledge Transfer in STEM Education

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Comparison of game-based learning and traditional lecture approaches to improve student engagement and knowledge transfer in STEM education: Work in progress

Abstract

In the modern educational system, educators are constantly striving to increase student engagement. Improving student engagement leads to an increase in learning motivation, ultimately enhancing students' ability to grasp complex topic areas. A common strategy to achieve higher engagement levels in the classroom is game-based learning (GBL). GBL has received mixed reviews due to a lack of data comparison and the difficulty of balancing entertainment with educational value. The objective of this study was to investigate how student knowledge transfer compares between a GBL activity and a traditional classroom lecture within STEM education. The GBL activity developed for the study was a cooperative board game called Preservation. During the game, players worked together to mitigate a tide of environmental threats related to the corn-water-ethanol-beef system in the Midwest. The primary learning outcomes measured during the study were student attitudes towards the environment and their capacity for systems thinking. Students in two junior level undergraduate courses completed pre-post-surveys after experiencing one of three treatments: group one – played Preservation, and group two – played Preservation with supporting lecture. Assessment focused on changes in student attitudes and overall understanding of system interactions. Initial findings suggest that the combination treatment provided the greatest change in systems thinking, however, no change occurred with respect to environmental attitudes. The results of this study will be used to direct the development of subsequent games and hands-on activities to promote transformational learning strategies in STEM education.

1. Introduction

Engagement in school is one of the primary building blocks to a successful educational system. Fredricks et al. preformed a literature review on the outcomes of effective engagement, finding evidence for improved achievement and lower dropout rates [1]. However, maintaining student engagement in the classroom has become increasingly difficult in recent years. Students are constantly being pulled to multi-media devices, which provide a level of entertainment that is difficult to match in the classroom. Consequently an emphasis has been placed on developing teaching strategies to improve student engagement including Active Learning, Flipped Classroom, and, the focus of this research, Game-Based Learning (GBL).

GBL has been defined many ways in the literature, but for this study, it will refer to any approach that uses a game (digital or hard copy) developed to produce specific educational learning outcomes. This is slightly different from the term "Serious Games" which generally only refers to digital games where entertainment is not the primary objective [2].

The interest of academics in GBL stems from the fact that youth are playing an increasing number of games, with 97% playing at least one hour per day [3]. Games are also designed to provide continual entertainment resulting in an engaging learning environment [4]. Additionally, the immersive experience provided by gameplay reduces the perceived effort for problem solving [5]. This engagement and perception of lowered effort provides educators a possible avenue to teach complex topic areas.

The literature perspective on GBL is highly varied. The primary reason is a lack of empirical evidence due to the relative newness of its popularity [6]. To better understand the status of GBL, several recent literature review studies have been performed to identify misconceptions and/or gaps in knowledge. In a study by Ke et al. [7], GBL's foundation of improving engagement was investigated to provide empirical evidence to its authenticity. Their findings indicate that GBL does provide an engaging learning environment, but the type of engagement transforms throughout the gameplay experience. In the review by [6], GBL papers from 2000 to 2013 were analyzed to compare quality applications of GBL. They concluded that in order to empirically prove the effect of GBL in primary education, more studies were necessary in comparison to traditional approaches, collaborative gameplay, and impact of 2D vs 3D games.

GBL has been identified in many studies to be a promising approach to improve classroom engagement, and provide an effective environment for problem solving [2], [4], [5]. However, arguments have been made that there currently isn't enough definitive evidence to holistically validate these claims [6]. The objective of this study is to provide empirical evidence on how student knowledge transfer compares between a GBL activity and a traditional classroom lecture within STEM education.

2. Methods

2.1. Sample

Two junior level undergraduate courses accepted to take part in the study (Course A and Course B), accounting for 70 students in total. Within this population are three primary degrees including mechanized systems management, biological systems engineering, and agricultural engineering. All students were 19 years of age or older and provided consent to be included in the study. Only results for Course A are presented in this paper as Course B testing is still in progress. The study was approved by the UNL Institutional Review Board #: 20180117955EX.

2.2. Intervention

2.2.1. Lecture Material

The curriculum developed for the in-class lecture was split into two primary topics: environmental sustainability and game theory. The first activity for environmental sustainability was a fishbone diagram designed to teach students about the cause and effect of agricultural management practices. A Fishbone diagram is a tool for root-cause analysis. It is similar to a tree diagram in that it starts at a broad topic, and continues to branch until the source is reached. During the activity, students were prompted to identify the source of environmental hazards, grouped into the major categories land use, chemical pollution, climate change, and fresh water use. As students progressed to the root cause of each of the issues, the teacher prompted a discussion on how individual components combine to influence the entire system. See Figure 1 for the fishbone diagram layout used in the study.

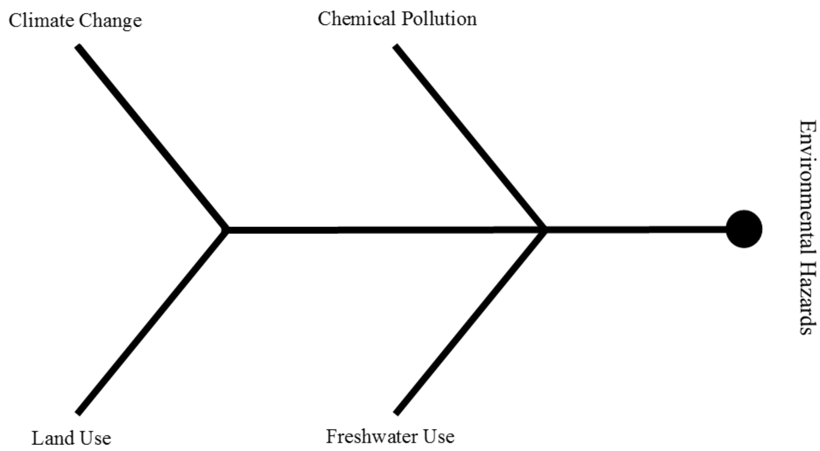

Figure 1. Fishbone diagram for cause and effect relationships within the CWEB nexus.

The second environmental sustainability activity introduced the students to the Resource Management Hierarchy, see Figure 2. During this activity, students were given 19 management decisions and were instructed to match each with the appropriate level. Many of the decisions were purposely designed to match multiple categories, allowing the students to debate the correct answer. After completing the matching activity the teacher prompted the students to discuss how they use each of the five categories in their daily lives.

Figure 2. Resource management hierarchy for sustainable decision-making.

For the game theory lecture, students were introduced to basic principles and definitions using the "Prisoner's Dilemma" [8]. Students then preformed two classroom activities during which they competed against one another using game theory principles. The first activity, titled *The Farmer's Dilemma,* had the students decide if they should advertise their products. The potential outcomes seen in Figure 3 were given to the students, and after competing three rounds in pairs they determined who made the most money. After tabulating the results, a discussion was made on why the groups trended toward a certain direction and examples of this occurring in real-world situations.

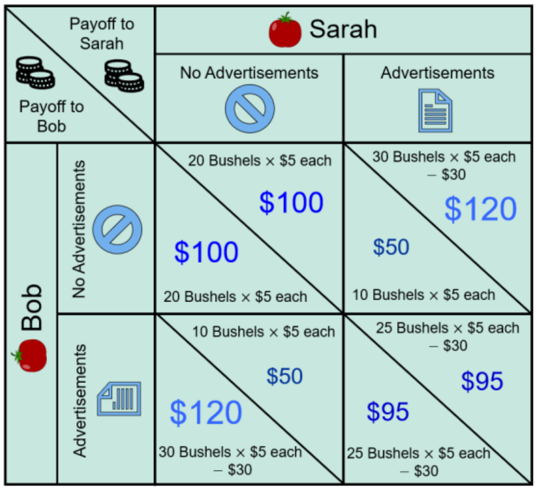

Figure 3. Farmer's Market Dilemma outcomes for each of the four possible scenarios.

In the final game theory activity, titled *80% of the Average*, the class worked together to determine when the best time was to sell their corn. Students were given a scenario where they were told their corn had just been harvested and they can store it for a maximum of 100 days. Based on research, the most effective time to sell is when 40% of the corn has been sold. Students were then asked to discuss with their classmates at what time they were going to sell their produce. After discussing, they wrote down their actual sell time ranging from 1 day to 100 days. The ideal time was calculated and a class discussion was performed on why students chose the date they did. Throughout all of these activities, candy was used as an incentive for winning or completing scenarios.

2.2.2. Game Activity – Preservation

The game activity developed for the study was a cooperative board game called Preservation. It is a 2-4 person game focused on environmental sustainability within the corn-water-ethanol-beef nexus in the Midwest. The goal of the game is to unlock four technological advancements, one for each of the environmental threats: Land Use, Climate Change, Chemical Pollution, and Fresh Water Use. To do this, players collect technology cards containing advancements. These advancements are based upon a review of literature in agricultural technology. The players' adversary is a tide of environmental threats that grow in magnitude over the course of the game. If these threats are left unmanaged, they rapidly expand ending any hope of a sustainable environmental system. With an interchangeable game board, eight character roles, and random card placement, students must navigate a unique game scenario each time they play.

2.3. Data Collection

Classes were split into two groups with each group receiving a different intervention listed as follows Class A Group 1 – game only, Class A Group 2 – game+lecture, Class B Group 1 – Lecture only, and Class B Group 2 – game+lecture. Two survey instruments were used in the data collection procedure. The Environmental Attitudes Inventory developed by Milfont et al. was used to measure changes in students' attitudes toward environmental sustainability [9]. To reduce the time of the survey, the shortened version was implemented, and blocks were removed to better align with the study's learning objectives. Metrics included in the study include Enjoyment of Nature, Confidence in Science and Technology, Environmental Threat, Personal Conservation Behavior, and Human Utilization of Nature. The finalized survey consisted of 30 Likert scale questions that can be seen in Appendix A.

The second instrument, designed by Evagorou et al., was used in the study to test students understanding and ability to use systems thinking [10]. The survey uses a variety of questions including short answer, diagraming, and numeric solutions. The instrument was designed to identify four main characteristics users contain when effectively using systems thinking. These include identification of system boundaries, temporal boundaries, sub-system elements, and system interactions. Questions escalade in comprehension as the survey progresses from basic to advanced systems thinking characteristics. For more information on the exact instrument used in the study, see Appendix B.

2.4. Evaluation

Survey results were evaluated using independent sample t-tests. Mann-Whitney U tests were used to confirm t-test results. Instrument reliability was checked using Cronbach's Alpha, with all metrics maintaining within the acceptable level.

3. Results

Survey results for the first junior level engineering course are given in the following section. Table 1 indicates the syntax and sample size used throughout the evaluation procedure unless otherwise stated. Comparisons between the student's pre-test and post-test surveys for systems thinking are reported in Tables 2. No significant changes occurred between the pre-test and post-test. The average score for all questions remained relatively constant with the pre-test scoring 3.29 and the post-test 3.27 (t=-0.133 and p = 0.895). The largest change came from the Q3: Temporal boundaries were students' scores fell from 3.09 to 2.79 (t=-0.816, p=0.416).

Table 1. Samples used in reporting and evaluation for systems thinking.

Sample	Sample Size (n)	Description
Pre-test	28	All Pre-surveys taken by the class
Post-test	23	All Post-surveys including game only and game+lecture
Post-game	10	Post-surveys for game only
Post-game+lecture	13	Post-surveys for game+lecture

Table 2. Systems thinking grades: Comparison of Pre-Test and all Post-Tests

Item	Pre-test	Post-test	Mean Difference	t-statistic	p-value
Systems Thinking - Overall	3.29	3.27	-0.02	-0.133	.895
Q1: System Elements	3.13	3.32	0.19	0.633	.529
Q2: Spatial Boundaries	3.53	3.66	0.13	0.489	.627
Q3: Temporal Boundaries	3.09	2.79	-0.29	-0.816	.419
Q4: Sub-System Elements	3.46	3.35	-0.11	-0.391	.697

Table 3 reports the comparison of interventions, Post-game and Post-game+lecture, for the systems thinking survey. A significant difference exists between the overall scores of the Post-game and Post-game+lecture with 2.96 and 3.50 respectively (t=2.484 and p = 0.022). The only individual question to contain a significant difference was Q1: Identification of system element (t=2.513 and p = 0.020). The main outlier in the sample is Q3: Temporal boundaries were Post-game scored higher than Post-game+lecture with 2.91 and 2.69 respectively (t=-0.429 and p=0.673).

Table 3. Systems thinking grades: Comparison of Post-test Game and Post-test Game+Lecture

Item	Post-test Game	Post-test Game & Lecture	Mean Difference	t-statistic	p-value
Systems Thinking - Overall	2.96	3.50	0.54	2.484	.022
Q1: System Elements	2.71	3.78	1.07	2.513	.020
Q2: Spatial Boundaries	3.32	3.92	0.59	1.624	.121
Q3: Temporal Boundaries	2.91	2.69	-0.22	-0.429	.673
Q4: Sub-System Elements	3.02	3.61	0.59	1.457	.160

Table 4 reports the comparison between the Pre-test and Post-test surveys for the Environmental Attitudes Inventory research instrument. A significant change was not seen in any of the metrics. The average score for all of the questions remained constant with scores of 2.64 and 2.69 for pre and post respectively (t = 0.537 and p=5.94). The largest change occurred in the metric “Confidence in Science and Technology” with the Pre-test scoring 2.26 and Post-test 2.50 (t=1.253 and p =0.216).

Table 4. Environmental Attitudes Inventory survey results: Comparison of Pre-test and Post-test

Item	Pre-test (n=25-27)	Post-test (n=20-22)	Mean Difference	t-statistic	p-value
Environmental Attitudes - Overall	2.64	2.69	0.05	0.537	.594
Enjoyment of Nature	3.54	3.58	0.04	0.302	.764
Confidence in Science and Technology	2.26	2.50	0.24	1.253	.216
Environmental Threats	2.30	2.27	-0.04	-0.190	.850
Personnel Conservation Behavior	2.72	2.80	0.09	0.515	.609
Human Utilization of Nature	2.45	2.33	-0.13	-0.862	.393

Table 5 compares the differences in intervention strategies, Post-game and Post-game+lecture, for the Environmental Attitudes Inventory research instrument. Significant differences were not found for any of the metrics with the average score for all metrics remaining relatively constant (t=-0.536 and p=0.598).

Table 5. Environmental Attitudes Inventory survey results: Comparison of Post-test Game and Post-test Lecture

Item	Post-test Game (n=9-10)	Post-test Lecture (n=11-12)	Mean Difference	t-statistic	p-value
Environmental Attitudes - Overall	2.73	2.66	-0.07	-0.536	.598
Enjoyment of Nature	3.67	3.51	-0.15	-0.893	.382
Confidence in Science and Technology	2.60	2.42	-0.18	-0.618	.543
Environmental Threats	2.25	2.28	0.03	0.093	.927
Personnel Conservation Behavior	2.83	2.78	-0.06	-0.241	.812
Human Utilization of Nature	2.30	2.35	0.04	0.195	.847

4. Discussion

The goal of the study was to inspect the differences in learning outcomes based on varying educational interventions including game only, lecture only, and lecture+game. The game used during the interventions was a cooperative board game called Preservation focused around the Midwest's CWEB nexus. The learning outcomes used to evaluate intervention success were students' understanding of system stinking and attitudes to environmental sustainability.

Initial findings from Course A, indicate that the intervention game+lecture had a significant increase in systems thinking compared to game only ($t=2.484$ and $p=0.022$). These results lead to the assertion that supporting games through traditional classroom lecture material improves the success of teaching complex topics. However, these finding are still preliminary as Course B testing is still in progress, and contains the lecture only data necessary for a complete analysis of intervention strength.

Significant changes in the students' environmental attitudes were not seen for any of the metrics, and differences were not observed between intervention types. The lack of change regardless of educational strategy has prompted further inspection into the viability of the instrument to evaluate the project. A revised instrument is under development which shifts the focus from inherently held beliefs towards students' understanding of sustainability factors. Additional changes to instrument design are also being considered to address student feedback on the pre-post format. Students voiced their disdain with having to take the same instrument twice within a two-day period. From a research perspective, this increases the risk that students will not provide the same level of effort on both attempts skewing the results. Support for this speculation can be seen in the systems thinking results were students actually performed worse on average between Pre-test and Post-test. A potential solution being considered is switching from pre-post to retrospective.

The initial finding of this study indicate that the ability of GBL to bring about learning outcomes greatly depends on the intervention strategy. Future inspection into this research will provide clarity on whether GBL exceeds traditional lecture approaches, and if a synergistic effect exists when supporting GBL with traditional lecture material.

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Appendix A

Systems Thinking Survey

The following survey is designed to help you understand and build skills in **Systems Thinking**.

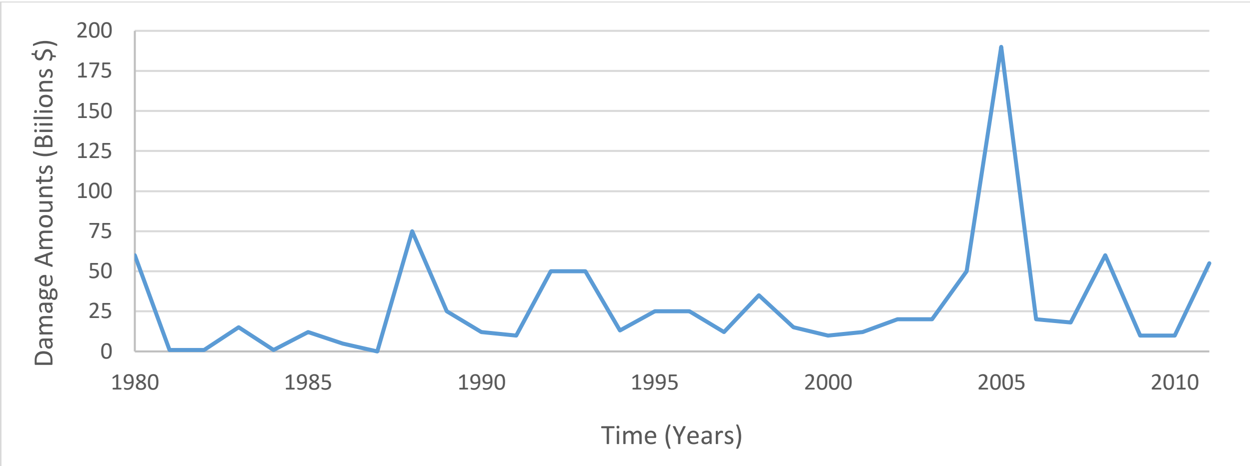
<u>Let's start with a definition of a system</u>. A **system** is a set of elements that interact with each other. For example, a forest may be considered as a system and it may have elements such as plants, insects, animals, reptiles, soil, rocks, water, etc. A **sub-system** is a smaller system that is part of a larger system. For example, a tree, pond, etc. may be considered as a sub-systems of the forest.

Instructions: Answer the following questions or problems to the best of your knowledge. Feel free to draw diagrams if it helps you in answering a particular question. There is no right or wrong answer. **Try your best!**

Q1: Name the various elements that make up a food system.

Q2: I would like to study the food system and how it operates. On the paper, draw a food system and mark the area that you think I should study.

Q3: Look at the graph below that shows the cost of climate disasters in the US on a yearly basis. The X axis on the graph shows the time in years and the Y axis shows the damage amount in billions of dollars. Notice how the damage amount varies with time



Q3 (i): How often will you like to assess the change in damage amount due to climatic events, knowing that each time you collect data costs you 1 million dollars and that damages above 25 billion influences the profitability of your regions farming operations?

Q3 (ii): Explain why?

Q4 (i): In your own words explain what do you understand by the term "system"?

Q4 (ii): In your own words explain what do you understand by the term "sub-system"?

Q4 (iii): Can you name any other smaller subsystems within the food system?

Appendix B

Environmental Attitudes Survey

Instructions: Answer the following questions to the best of your understanding. There is no right or wrong answer.

ID	Question	Strongly disagree				Strongly agree
1	I really like going on trips into the countryside, for example to forests or fields.	0	1	2	3	4
2	I find it very boring being out in wilderness areas.	0	1	2	3	4
3	Being out in nature is a great stress reducer for me.	0	1	2	3	4
4	I have a sense of well-being in the silence of nature.	0	1	2	3	4
5	I find it more interesting in a shopping mall than out in the forest looking at trees and birds.	0	1	2	3	4
6	I think spending time in nature is boring.	0	1	2	3	4
7	Science and technology will eventually solve our problems with pollution, overpopulation, and diminishing resources.	0	1	2	3	4
8	Modern science will NOT be able to solve our environmental problems.	0	1	2	3	4
9	We cannot keep counting on science and technology to solve our environmental problems.	0	1	2	3	4
10	Humans will eventually learn how to solve all environmental problems.	0	1	2	3	4
11	The belief that advances in science and technology can solve our environmental problems is completely wrong and misguided.	0	1	2	3	4
12	Modern science will solve our environmental problems.	0	1	2	3	4
13	If things continue on their present course, we will soon experience a major ecological catastrophe.	0	1	2	3	4
14	When humans interfere with nature it often produces disastrous consequences.	0	1	2	3	4
ID	**Question**	**Strongly disagree**				**Strongly agree**

15	Humans are severely abusing the environment.	0	1	2	3	4
16	The idea that the balance of nature is terribly delicate and easily upset is much too pessimistic.	0	1	2	3	4
17	I do not believe that the environment has been severely abused by humans.	0	1	2	3	4
18	People who say that the unrelenting exploitation of nature has driven us to the brink of ecological collapse are wrong.	0	1	2	3	4
19	I could not be bothered to save water or other natural resources.	0	1	2	3	4
20	In my daily life I'm just not interested in trying to conserve water and/or power.	0	1	2	3	4
21	I always switch the light off when I don't need it on any more.	0	1	2	3	4
22	In my daily life I try to find ways to conserve water or power.	0	1	2	3	4
23	I am NOT the kind of person who makes efforts to conserve natural resources	0	1	2	3	4
24	Whenever possible, I try to save natural resources.	0	1	2	3	4
25	Protecting peoples' jobs is more important than protecting the environment.	0	1	2	3	4
26	Humans do NOT have the right to damage the environment just to get greater economic growth.	0	1	2	3	4
27	Protecting the environment is more important than protecting economic growth.	0	1	2	3	4
28	Protecting the environment is more important than protecting peoples' jobs.	0	1	2	3	4
29	The question of the environment is secondary to economic growth.	0	1	2	3	4
30	The benefits of modern consumer products are more important than the pollution that results from their production and use.	0	1	2	3	4