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A Comparative Analysis of Game-Based Learning vs. Traditional Education in Promoting Sustainability Awareness among Students

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Abstract

Sustainability education plays a crucial role in enhancing awareness on global environmental issues and developing responsible behaviors among future generations. Conventional lecturing methods in teaching usually do not facilitate active student participation and long-term retention of sustainability concepts since they depend on passive learning. This has made the need for more interactive teaching strategies to enhance students' understanding and interest in sustainability. This paper examines GBL as an emerging strategy to bridge this gap. GBL combines interactive features of simulations, gamified quizzes, and role-playing to immerse students in the real world, thus fostering problem-solving skills. This research aims to compare how GBL compares with TE methods to enhance knowledge about sustainability, engagement, and overall outcomes. This is new in its application because it uses game-inspired activities to make learning more interactive. Findings show that GBL leads to significant gains in student performance and engagement. For instance, there was a 35% improvement in post-test scores concerning sustainability knowledge for the experimental group as compared to a mere 15% increase for the control group. Students in the GBL group also reported greater engagement and a higher likelihood to recommend the learning method, implying that the interactive nature of learning contributed to the success. This study indicates that GBL is a better alternative and more engaging when compared to traditional methods of learning, especially when dealing with complicated subjects like sustainability. This study, therefore, points out that it is possible to include GBL in curricula to have deep learning, critical thinking, and long-term retention of sustainability concepts.

Keywords- Engagement, Game-Based Learning, Knowledge Retention, Sustainability Education, Traditional Education.

1. Introduction

Sustainability awareness is growingly accepted as an important part of education in better equipping students to face the challenges of the 21st century [1]. It goes about such issues like climatic changes, natural resources depletion, as well as habitat destruction with tendencies toward destabilizing ecological balances in human society too [2]. Hence, efforts in a mitigation of the same rely more on teaching environmentally conscious young individuals' sustainability behaviors. Students, as future policymakers, innovators, and global citizens, have a unique role in driving change [3]. For this mission to be achieved, educational institutions can play the most important roles by providing the platforms for imparting sustainability knowledge and fostering ecological behaviors that will lead to a more sustainable future [4]. Despite being of importance, sustainability education often fails to reach its full potential because of outdated teaching approaches [5].

Traditional approaches, such as lectures and text-based learning, focus more on theoretical knowledge but do not always engage students actively or help them connect abstract ideas to practical use [5]. This lack of engagement can make students lose interest and retain less, which defeats the aim of developing true environmental stewardship [6] ,[7]. Therefore, innovative methods are required to fill this gap between theoretical knowledge and action-oriented awareness, thus motivating and preparing students to adopt sustainable practices [8], [9]. One of the hopeful answers lies in game-based learning (GBL), which uses the gamification principle to transform educational processes into interactive and engaging activities [10], [11]. GBL makes a learning process not like a traditional method; it turns it into an activity that is full of challenges, rewards, and a plot to trigger curiosity and deep understanding [12].

GBL could make sustainability education not only retain more knowledge but also help connect emotionally to issues with the environment [13]. Yet, the effectiveness compared with traditional education in improving knowledge about sustainability is less studied, requiring some focused research in that particular area [13].

1.1 Problem Statement

Despite the growing focus on sustainability education, a large gap exists in identifying the most appropriate teaching methodologies for imparting sustainability awareness among students[14]. Traditional methods of education have focused on the theoretical aspect of learning, not actively involving students in hands-on and experiential learning [15]. On the other hand, game-based learning provides an innovative approach to the process by applying gamification principles to make learning interactive, enjoyable, and immersive [16]. While there is evidence to suggest that GBL increases student engagement and helps students remember information better, few studies have investigated whether GBL promotes sustainability awareness compared to the traditional approach of teaching [17]. The lack of empirical evidence leaves educators unsure about which strategies will most effectively create lasting and meaningful sustainability awareness in their students.

1.2 Research Goal

To conduct a comparative analysis of game-based learning (GBL) and traditional education in promoting sustainability awareness among students. To evaluate the relative effectiveness of both methods in terms of:

- ✓ Student engagement.
- ✓ Knowledge retention.
- ✓ Behavioral changes towards sustainability.

1.3 Contributions of the Study:

Actionable insights into providing the evidence to guide educators and curriculum designers to design more effective teaching strategies in sustainability education.

Innovative Pedagogy: Identify the strengths and limitations of GBL and the traditional methods, emphasizing their practical applications in the classrooms.

Policy Recommendations: Provide useful inputs to policymakers willing to incorporate effective strategies of education towards sustainability into the national curriculum.

Empower Future Generations: Support the wider purpose of preparing students with knowledge and motivation to become actively involved in solving global environmental problems.

Advancement of Research: Fulfils the gap in literature pertaining to the effectiveness of game-based learning in fostering sustainability awareness as compared with more traditional methods.

1.4 Research Aim and Objective

Research Aim:

Comparing Game-Based Learning and Traditional Education to see which better facilitates sustainability awareness among students: the knowledge, engagement, and perceptions change.

Research Objectives:

1. Evaluate the change in sustainability awareness among students subjected to GBL and TE.

2. Compare the levels of student engagement and participation in sustainability-related activities between the GBL and TE groups.

3. Determine how students retain sustainability concepts following involvement in either GBL or TE.
4. Collect and analyze qualitative feedback from the students regarding the learning experience with GBL and TE.
5. Establish the perceived strengths and weaknesses of GBL as against TE in the facilitation of sustainability education.

Research Hypotheses

H1: Students exposed to game-based learning will exhibit a significantly better increase in sustainability awareness, as compared to those exposed to the traditional education approach.

H2: Students exposed to game-based learning will exhibit greater engagement as well as motivation towards sustainable learning, compared to students exposed to the traditional education approach.

H3: Students who are engaged in Game-Based Learning (GBL) will have better recall of sustainability concepts than students who take Traditional Education (TE) in a post-assessment test.

Research Questions

RQ1: To which extent does Game-Based Learning (GBL) enhance the awareness of students about sustainability compared to the Traditional Education (TE)?

RQ2: To what extent and in what ways do the engagement levels and participation of students into sustainability learning differ between GBL and TE?

RQ3: What is students' perception of the efficiency and benefits of Game-Based Learning compared with Traditional Education in sustainability learning?

The rest of the paper is structured as follows: Section 2 introduces the relevant work done regarding Game-Based Learning (GBL) and Traditional Education (TE) approaches within the framework of sustainability education. Section 3 describes the proposed methodology including the design of the GBL framework and its interactive elements such as simulation and quizzes for the awareness of sustainability. Section 4 shows the results and discussion of the comparative effectiveness of GBL and TE using pre-test and post-test scores, engagement metrics, and content understanding. Lastly, Section 5 delivers the conclusion, which sums up the results and outlines future directions for GBL implementation into sustainability education.

2. Related Works

Ho et al.[18] seeks to explore if game-based experiential learning contributes to more effective comprehensive environmental education. With interactive and immersive ways of learning, the research showed immense improvement in the public understanding of social and environmental problems and brought positive attitudes toward development. However, the study suffers from no direct comparison of gamified and traditional approaches, opening up potential avenues for future research regarding their relative effectiveness. Thus, sustainability education can potentially provide deeper learning and awareness with the help of gamified learning.

The study "Game-Based Learning Sustainability during Social Distance: The Role of Gamification Quality" published in 2022 deals with the acceptance of gamification in online learning settings with factors such as quality of gamification, instructor-related variables, and technology anxiety among the ERP-based gamified courses. It showed that student satisfaction and perceived ease of use had a significant impact on acceptance and perceived usefulness of the gamified tools, bringing about an improved learning experience. However, the findings of the study indicated that technology anxiety did not influence perceived usefulness, probably due to the fact that online learning is mandatory during the COVID-19 pandemic, which forces students to ignore the drawback of gamification [19].

Ghosh et al.[20] based on the design and application of simulation games that reflect real-world systemic challenges, allowing participants to work through sustainability issues in an interactive, dynamic environment. The study experimented with these game-based approaches to test the efficiency of games in fostering critical thinking, collaborative decision-making, and the exploration of sustainable solutions. Results: Game-based learning was a significant means of improving complex, interconnected environmental problems, encouraging creative problem-solving, and policy innovation in participants. This allowed the respondents to visualise the effects of some of the choices in the long run. Thus, this gave them much deeper appreciation for the issues at play with sustainability transitions. In addition, these results notwithstanding, it was stated that the game-based learning could be more effectively analyzed and reviewed to determine real-world policymaking relevance. It focused on the need to scale up these approaches and to evaluate their effectiveness in changing actual policy decisions and their potential to trigger lasting systemic change in sustainability practices.

Costin, O'Brien, and Hogan [21] examined how GBL can be used in sustainability education. It investigates several gamified educational interventions which have been designed to promote student learning toward sustainable development and environmental awareness. The investigation found that GBL approaches showed a significantly enhanced engagement capacity of the students by making them find topics related to sustainability more appealing and interactive. These challenge elements included rewards and competition to increase students' motivation for promoting sustainable behaviors, helping in improving their knowledge regarding difficult questions associated with sustainability. GBL facilitates students in making more deep interactions of the material through conversion of the whole learning process into a lively enjoyable game-based activity. Yet the paper also made a call for further studies, especially in longitudinal directions, to observe the sustainability practice of the students influenced by GBL over time. It, therefore, necessitated how sustained engagement with gamified methods impacts students' behaviors over a considerable time. It hinted that more intensive research could probably provide insights about the sustained impact of game-based learning on real-life outcomes of sustainability.

Scurati et al. [22] investigated whether a board game designed to learn sustainability risks and opportunities in product development and life cycles can help. Several student groups received the game, and their effectiveness was assessed through questionnaires and qualitative analyses of responses. The findings proved that the game successfully engages students and enhances their knowledge about the sustainability challenges facing product development, promoting collaborative learning and critical thinking. Interactive and hands-on methods enable them to visualize and understand complex issues concerning sustainability. However, the study took into account several limitations for instance, the pilot project was relatively small and suggested further research with larger size and more diverse samples to allow for validation and generalization. Broader studies are necessary to identify the long-term impact of such game-based learning techniques in sustainability education.

Pineda-Martínez et al. [23] focused on the use of video games, gamification, and game-based learning in sustainability education. This work used the PRISMA methodology in the review process. The synthesized findings from nine selected studies detail how game-based approaches were utilized to improve student engagement and deepen their understanding of sustainability-related concepts. These methods have really proved effective in promoting a spirit of collaboration and cooperation for enhancing social skills, key in fostering sustainability in real-world contexts. Interactive and participatory gamification facilitated greater engagement with complexity and abstractness of such issues as sustainability. In addition, the research highlighted that game-based learning is beneficial in allowing students to perceive the long-term implications of environmental decisions, thereby developing more sustainable practices. The authors suggested that further research is needed to understand how GBL can be more effectively used and the impact on actual sustainability practices outside the university setting, but robust data would be required to make such an assessment of the value of game-based learning in this area.

Jääskä, Aaltonen, and Kujala [24] examined GBL approach in teaching project sustainability management with a focus on making the learning experience exciting while ensuring that positive impacts would be derived. Indeed, real-world sustainability issues would provide an effective means through the GBL of imparting understandings to students through simple real-life experiences regarding otherwise knotty complexities encountered in project management. The findings focus more on the strong appropriateness of game-based learning for sustainability education in a context where it fosters cooperation, critical thinking, and practical problem-solving abilities all required in managing sustainable projects. Though promising for improving the level of engagement and better results, this study fails to define its limitations; this therefore raises further research as regards ascertaining how wide it applies and impacts on a sustainability education in a long term and at work settings.

Jarrah et al. [25] presented the research questions focused on assessing the role of the ABACUS digital game-based learning tool in enhancing the understanding of fractions among students in the United Arab Emirates. A quasi-experimental design was adopted, with the sample grouped into a control group and an experimental group. Two groups of students were pre- and post-tested to establish whether the ABACUS intervention was effective. Results obtained in the post-test revealed that experimental students, who utilized the ABACUS tool, were more significant than the control students. This implies that DGBL, especially the ABACUS tool, can be used as a substitute method for teaching tricky mathematical concepts, like fractions. Curriculum planners should also introduce digital games in educational institutions to encourage student engagement and understanding, according to this study. Findings from these studies also confirm more general research conducted on the issue, which notes that DGBL is a suitable method for achieving better outcomes in education, especially math, by ensuring an engaging and interactive process of learning.

The overall limitation of studies on DGBL is small sample size, which limits the generalizability of the findings, and longitudinal data are rarely available to assess the long-term effects of DGBL on students. In many cases, studies lack direct comparisons with traditional methods of education, making it difficult to determine whether DGBL is more effective or just an alternative. Additional limitation with other studies is not being concerned with technology-related problems; hence, there will always be technology anxiety and an associated threat for a student's ability to use such a tool. Other limiting issues of the studies have tended to focus on some specialized discipline, thus giving minimal insight into the broad general applicability of DGBL. Most times, data analysis methods have proven inadequate, thus restraining robust findings. Additionally, implementing and scaling DGBL in varied educational contexts proves challenging and requires more studies on the practicability and feasibility of the intervention. These constraints point out to the requirement of much wider and stringent research on truly assessing the impact of DGBL in the teaching-learning processes.

3. Methodology: A Mixed-Methods Approach to Evaluating the Effectiveness of Game-Based Learning vs. Traditional Education in Enhancing Sustainability Awareness Among Students

This methodology delineates a step-by-step procedure for conducting a study on the comparison of sustainability awareness through GBL compared to TE. The process involves being systematic, with mixed analyses of both quantitative and qualitative as shows in the Figure 1. Below is a further elaboration of the steps of this process, including use of primary data, in terms of dataset and the survey results, statistical equations, and tables.

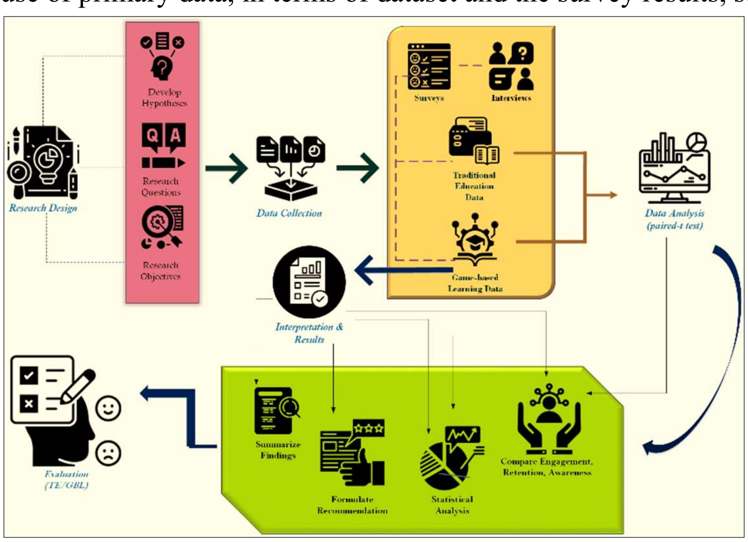

Figure 1: A Mixed-Methods Approach to Evaluating the Effectiveness of Game-Based Learning vs. Traditional Education

3.1 Research Design

The Analysis customs quasi-experimental design to gauge and compare the effectiveness of GBL in comparison to TE in promoting the awareness of sustainability among students. The design has two groups:

a) **Experimental Group (GBL):** Participants in this group will be exposed to interactive, gamified learning activities focused on sustainability.
b) **Control Group (TE):** This group will be instructed using the traditional classroom approach with lectures, textbooks, and discussion on the sustainability concepts.

The study employs pre-tests and post-tests to capture changes within each group regarding awareness of sustainability. This enables the assessment of how effectively GBL is compared to TE in improving knowledge and the understanding of the student for sustainability.

3.2 Participant Selection Process

Participant Selection, this is an important procedure that ensures that the final results of the study will be valid and reliable. It ensures that the target population is fairly represented and that the Experimental and Control groups are not different in other important characteristics that could contribute to biasing the data. This procedure minimizes bias and the probability of extraneous influences. In this process, there are three main steps:

3.2.1 Sample Population Identification

The first step is to choose an appropriate sample population from the target group, which could be students from schools or universities. It aims to have a representative group of participants who are diversified in terms of educational levels, age groups, and demographic characteristics such as gender and socioeconomic status, as shown in the Table I. Again, the sample should relate well to the scope that covers the study, and samples may be drawn at both high school students' or university undergraduates up to their graduate level. Its sample size is determined as statistically powered to meet such or related requirements, in as much as power analyses were conducted for the case.

Table I: Sample Population

Participant ID	Grade Level	Prior Knowledge	Group Assignment
1	High School	Low	GBL
2	University	High	TE
3	High School	Medium	GBL
4	University	Low	TE

3.2.2 Stratification

The selected sample then undergoes stratification whereby subgroups of that sample are ensured to have balanced representation in the Experimental group that will receive the treatment and the Control group without treatment. This allows ensuring critical variables that could be associated with effects from differences, such as preexisting knowledge of sustainability concepts, grade performance, and age, are spread across the groups. This is particularly crucial if there is a belief that these factors could possibly affect the effectiveness of learning methods. The sample stratification is given in Table II.

For instance, if the study would anticipate that students with more basic knowledge about sustainability have better chances of performing, it would stratify based on the level of knowledge or say, beginner, intermediate, advanced. This way, in a similar composition, the GBL group will contain students from different knowledge levels and so the TE group, thus being able to compare the interventions more effectively. Stratification is feasible with the use of the demographic data.

- **Grade Level:** Balanced student distribution from various levels of academic progression.

- **Prior Knowledge of Sustainability:** Groups the students according to whether they have prior experience or knowledge of sustainability.
- **Demographic Factors:** Assuring that all demographics be represented, such as gender or socioeconomic background.

Table II: Stratification of Participants Based on Knowledge Level, Grade Level, and Gender

Stratum	Knowledge Level	Grade Level	Gender	Number of Students
1	Beginner	9th Grade	Male	10
2	Intermediate	10th Grade	Female	10
3	Advanced	12th Grade	Male	10

3.2.3 Random Assignment

Following stratification, the next major action is random assignment where each student is randomly allocated to either the Experimental Group (GBL) or Control Group (TE). There is always a need to ensure through random assignment that any differences observed between these groups would be due to the intervention, either being GBL or TE, as in Table III. This helps minimize selection bias, since at the outset of the study, the two groups would be quite similar, meaning that factors such as motivation, interest in sustainability, or academic aptitude are distributed evenly in both groups, reducing systematic bias. Random assignment can be performed through very basic methods like a random number generator or even with more sophisticated statistical software, for example, R, SPSS, or Excel. After randomization, each group will receive a different intervention: GBL for the Experimental Group, and traditional education for the Control Group. The content itself that will be delivered for both groups will be in the same sustainability awareness content, but the method in which the teaching is conveyed will be different, to enable direct comparison of GBL with traditional education for effectiveness.

Table III: Random Assignment of Participants to Experimental (GBL) and Control (TE) Groups

Stratum	Assigned to Experimental Group (GBL)	Assigned to Control Group (TE)
1	5 students	5 students
2	5 students	5 students
3	5 students	5 students

3.3 Curriculum Development for Experimental and Control Groups

This is the curriculum for both the GBL, and the Control Group. The idea here is to deliver the same content on sustainability but through different delivery methods, so as to test whether GBL has an impact on the awareness of sustainability among students when compared with TE.

3.3.1 Designing the Game-Based Learning (GBL) Module

For the Experimental Group, a Game-Based Learning module is designed. This module includes interactive features such as:

- **Simulations:** It is a virtual or virtual environment where students can experience the application of sustainability concepts through real-life situations, such as sustaining a virtual ecosystem or solving various sustainability challenges.
- **Gamified quizzes:** It will be interactive quizzes in which students earn rewards or points based on correct answers for better engagement and retention.

- **Role-Playing Scenarios:** Activities involving students in role-playing of being environmental managers or policymakers, thus giving them experience in the real-world applicability of sustainability issues.

The GBL module will enable the students to engage longer in the key concepts being learned, such as climatic change, conservation of resources, and proper handling of waste.

3.3.2 Developing the Traditional Education Curriculum

For the Control Group (TE), a traditional curriculum is created. This curriculum is exactly the same as the content of the GBL module but is taught in the traditional way:

- ✓ **Lectures:** Lectures by the teacher on sustainability topics.
- ✓ **Textbooks:** Printed or digital textbooks providing information on sustainability.
- ✓ **Classroom Discussions:** Organized discussions where the teacher leads students in a conversation about sustainability issues.

In traditional education curriculum, the contents given to the control group would be similar to that given to the experimental group, making direct comparison in terms of the method of teaching possible.

3.3.3 Ensuring Content Consistency

There's consistency to provide both groups with exactly the same content. Otherwise, the differences in what will happen afterwards may be attributed not by method but by content presented; hence, the similarities regarding the topics to be taken between the GBL and the TE groups are as follows in Table IV.

- o Sustainability and Climate Change
- o Renewable energy and resource conservation.
- o Sustainable Agriculture and Waste Management

This alignment ensures that any differences observed in student performance are truly due to the mode of learning rather than variations in content delivery.

Table IV: Curriculum Overview for Experimental and Control Groups

Topic	**Experimental Group (GBL)**	**Control Group (TE)**
Climate Change and Global Warming	Interactive Simulation on Climate Change	Lecture on Climate Change
Renewable Resources	Gamified Quiz on Renewable Energy	Textbook Reading on Renewable Energy
Waste Management	Role-Playing on Waste Reduction	Class Discussion on Waste Management

3.4 Assessment and Evaluation

To assess the effectiveness of the curricula, pre-tests and post-tests are given to both groups. This will help in measuring how much students know about sustainability before the intervention and the gains they make after the intervention. The tests include:

- ▪ **Objective Questions:** These could be multiple-choice or true/false questions that assess factual knowledge of sustainability.
- ▪ **Open-Ended Questions:** Questions on higher-order thinking, including solving problems as well as critical thinking in areas of sustainability.

The pre-test is administered before the intervention to determine the pre-intervention level of knowledge, and the post-test is administered after the intervention to determine the learning gains.

***Administering the Test*:** Participants of both groups undergo the same pre-test at the beginning of the study. This ensures that data collected is not biased. Results are taken to determine baseline knowledge, as shown in Table V.

Table V: Baseline Pre-Test Scores of Participants Across Experimental and Control Groups

Participant ID	Group	Objective Score (10)	Open-Ended Score (10)	Total Score (20)
1	Experimental (GBL)	5	6	11
2	Control (TE)	6	5	11
3	Experimental (GBL)	7	8	15
4	Control (TE)	5	4	9

Equation for Percentage Improvement in Knowledge is represented in Eqn. (1).

$$\text{Percentage Improvement} = \frac{\text{Post}-\text{Test Score}-\text{Pre}-\text{Test Score}}{\text{Pre}-\text{Test Score}} \times 100 \quad (1)$$

The Pre-Test Assessment ensures that knowledge is systematically and without bias at baseline, thus ensuring valid comparisons of learning outcomes from the Experimental (GBL) and Control (TE) groups. The instrument uses both quantitative and qualitative metrics: scores and open-ended responses, to enable a holistic measurement of sustainability awareness.

3.5 Intervention Phase

The core of the methodology is the Intervention Phase, which involves applying actual teaching methods to GBL and TE. This phase delivers identical content using two different approaches in instruction in order to determine which would better encourage sustainability awareness.

3.5.1 Experimental Group (GBL)

This group is taught through immersive and interactive learning methodologies based on Game-Based Learning (GBL), a strategy that works to increase motivation, drive active participation, and boost the understanding of sustainability subjects. Contrasting traditional approaches, GBL applies gamification principles-like rewards, challenges, or real-time feedback-to turn educational content into engaging dynamic experiences. Interactive simulations, role-playing scenarios, and digital challenges that mimic environmental and sustainability dilemmas ask students to solve real-world problems. For example, it may be the management of virtual city resources in harmony with economic growth and the preservation of ecology, or participating in gamified quizzes where a student is rewarded for accurate and fast responses with points or badges. GBL will therefore not only make complex concepts more accessible but also stimulate critical thinking, problem-solving, and collaboration among the students. Learning, thus, becomes both impactful and memorable, which lays a way for meaningful behavioral changes in their understanding and application of sustainability principles.

a. Interactive Sessions

They take part in dynamic game-like activities, like simulations and role-playing. For example, manage a virtual city's resources in a simulation. There, students could decide the usage of renewable energy and waste management practices while promoting water conservation through economic growth and environmental sustainability.

Learning Goals: Immerse students in real-world sustainability challenges to improve problem-solving skills. Encourage active participation and decision-making.

b. Gamified Quizzes

Each session ends with quizzes that use game mechanics including points, rewards, and levels. For instance, one can ask students questions, such as:

✓ Which of the following is a renewable energy source? (Options: a) Coal, b) Solar energy, c) Natural gas, d) Oil); thus, there is active learning and assessment.

c. Learning Outcomes:

Emphasis is put on developing problem-solving and critical thinking skills. Engagement metrics, such as average scores for quizzes and time on tasks, are tracked.

d. Engagement Metrics for GBL

Engagement data captures the average time spent per activity and average quiz scores to identify the impact of GBL. It is depicted in Table VI.

Table VI: Engagement Metrics for Experimental Group (GBL)

Activity	**Average Engagement Time (minutes)**	**Average Quiz Score (out of 10)**
Virtual Ecosystem Simulation	45	8.5
Renewable Energy Management Game	50	9

3.5.2 Control Group (TE)

This segment is trained by a classical mode of learning in which lecture and group discussions are primarily adopted as methods to present the sustainable principles.

a) Lecture-Based Learning

The trainers employ texts, slides, and narration as methods for the imparting of material such as climatic changes, green energy, and waste generation.

Learning Outcomes:

- Implies systematic presentation in the acquisition of knowledge
- Stress upon theory
- Group Discussions

Trained in class guided discussion to find solution on sustainable challenges.

b) Class Discussions Criteria

Participation in discussions and understanding of theoretical content are observed for comparison with the GBL group.

Evaluation Metrics: Discussion participation and understanding of the theoretical content are recorded for comparison with the GBL group.

Consistency in knowledge delivery: The same topics as in GBL are addressed here so that any difference in outcome would be attributable to the method of instruction and not to the content.

Table VII: Engagement Metrics for Control Group (TE)

Activity	**Average Engagement Time (minutes)**	**Average Quiz Score (out of 10)**
Lecture-Based Session	50	7
Class Discussion	30	6.5

3.6 Post-Test Assessment

The Post-Test Assessment is an essential step to determine the intervention's influence on the sustainability awareness among the students. It was aimed at assessing changes in knowledge and higher-order thinking skills development of the Experimental Group, which underwent Game-Based Learning, and the Control Group, which used Traditional Education. The two major parts of the post-test were Objective Questions and Higher-Order Thinking

Questions, respectively assessing both factual knowledge and the application and analysis ability regarding sustainability.

- Use the identical standardized test for sustainability awareness used on the previous pre-test with both groups post-intervention. It is ensured:
- It also has objective and open-ended questions to measure whether sustainability knowledge and critical thinking have improved.
- The post-test assesses higher-order thinking skills, such as problem-solving, analysis, and application of sustainability concepts.

3.7 Data Collection

Data collection step in this study is quite important because, based on the research collected, it shall be of prime importance for the purpose of evaluation between GBL and TE techniques to show a comparison if the method affects sustainability awareness. It comprises two principal forms, one quantitative, and another one qualitative in nature, giving valuable data about students in their learning procedures. Figure 2 depicts precisely the process of obtaining both quantitative and qualitative data in the sustainability awareness study.

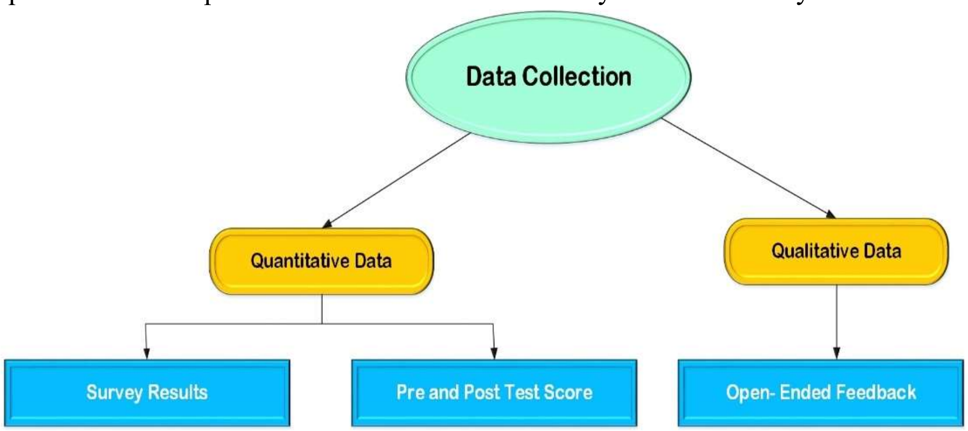

Figure 2: Data Collection Process for Sustainability Awareness

3.7.1 Quantitative Data

Quantitative data gathering involves obtaining numerical data, which could be analyzed statistically to deduce the interventions' success. These are gathered via the Pre- and Post-Test Scores and Survey Results.

Pre- and Post-Test Scores: Quantitative data primarily emanate from the scores on pretest and post-test before and after an intervention regarding knowledge acquisition related to concepts of sustainability among the students. Pre-tests occur right before an intervention is instituted, and post-tests right after it ends. In this study, these comprise both objective and higher order questions meant to establish both facts and practical applications about issues of sustainability.

For instance, a test scorer may score 50% on the pretest and 80% at the post-test showing enhancement in knowledge about sustainability. His or her change in the marks can be calculated as in Eqn. (1)

For the two groups, both Pre- and Post-Test Scores will be collected.

Survey Results: Gather students' attitude and engagement through the Likert scale, including the responses of 1-5 about how engaging the method of learning was for them, as in Table VIII.

Table VIII: Sample Survey Results

Participant ID	Survey Question: "How engaging did you find the learning method?"	Score (1-5)
1	4 (Somewhat Engaging)	4
2	5 (Very Engaging)	5
3	3 (Neutral)	3

4	4 (Somewhat Engaging)	4

3.7.2 Qualitative Data

Apart from the quantitative data, there is also qualitative data collected. This data offers deeper insights into the students' experiences with both methods of teaching, including the difficulties and advantages they faced.

Open-Ended Feedback will be gathered from the students about their learning experience, problems, and suggestions.

Table IX: Sample Pre- and Post-Test Results

Participant ID	**Pre-Test Score**	**Post-Test Score**	**Change in Score (%)**
1	50%	80%	30%
2	45%	70%	25%
3	55%	85%	30%
4	60%	75%	15%

In Table IX, the score change quantifies the percentage increase in the sustainability knowledge of students from the pre-test to the post-test. This table is one major quantitative measure to compare both the GBL and the TE interventions.

3.8 Data Analysis - Paired t-Test

The step Data Analysis in this research would be necessary to see how effectively the learning results obtained through GBL could differ from those of the students trained through TE. Thus, the differences between pre-tests and post-tests within groups must be measured. The most suitable method among the statistical methods in that scenario is the Paired t-Test, allowing to determine whether the scores in two related groups are equal based on the change within these groups.

Here is a step-by-step explanation of the analytical procedure, including the Paired t-Test formula and its components, as applied to this study. Figure 3 aligns with the process of analyzing the data regarding how effective the interventions have been using paired t-test analysis.

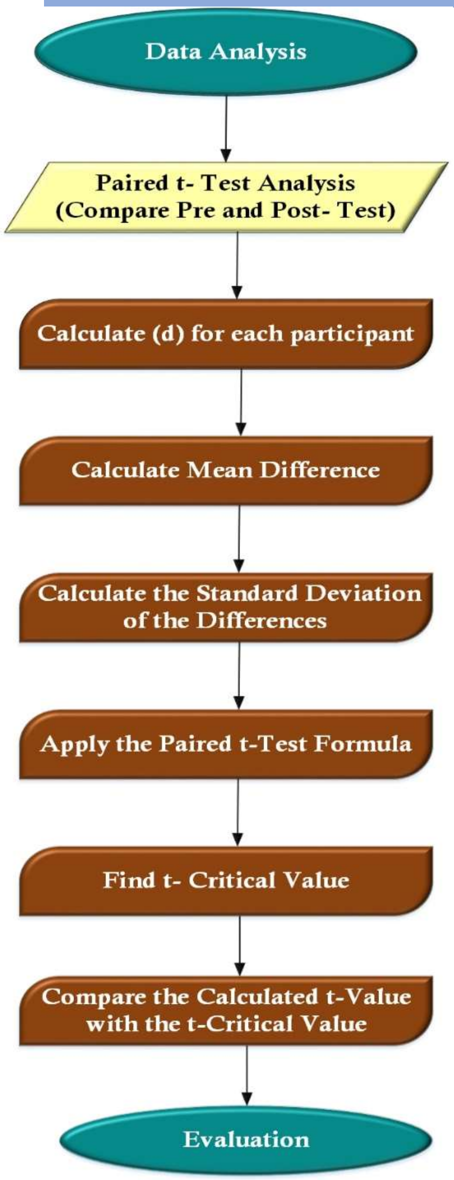

Figure 3: Paired t-Test Analysis Process for Pre- and Post-Test Comparison

1) **Calculate the Difference (d) for Each Participant**

For each subject, calculate the difference between the Post-Test Score and Pre-Test Score. This is denoted by d, which measures the effect of the intervention on their knowledge. It is mathematically calculated in the Eqn. (2).

$$d_{i=} \text{Post} - \text{Test Score}_i - \text{Pre} - \text{Test Score}_i \quad (2)$$

2) **Calculate the Mean of Differences ($\bar{d}$)**

The next step is to calculate the mean difference, ($\bar{d}$), for all participants. The mean difference is calculated as the sum of all the individual differences divided by the total number of participants in the Eqn. (3).

$$(\bar{d}) = \sum_{i=1}^{n} d_i \quad (3)$$

where, $\bar{d}$ differences of the mean, d_i each participants' differences.

3) ***Calculate the Standard Deviation of the Differences (S_d)***

Lastly, compute the standard deviation of the differences (S_d). Using computed differences and the mean difference the standard deviation may be computed in the Eqn. (4).

$$(S_d) = \sqrt{\frac{\sum_{i=1}^{n}(d_i-\bar{d})^2}{n-1}} \quad (4)$$

4) Apply the Paired t-Test Formula

Step four, that is, applying of Paired t-Test formula to look for significance in differences obtained above. The formula for the paired t-test as follows in Eqn. (5).

$$t = \frac{\bar{d}}{s_d/\sqrt{n}} \quad (5)$$

5) Determine Degrees of Freedom (df) and find the t-Critical Value

The number of degrees of freedom for the paired t-test is determined by Eqn. (6).

$$df = n - 1 \quad (6)$$

6) Compare the Calculated t-Value with the t-Critical Value

Compare the obtained t-value with the t-critical value from the Table X.

- If the obtained value of t-value is bigger than the t-critical one, then we reject the null-hypothesis (H 0) and state that there is a sign difference between the pre-tests and post-tests scores.
- If the determined t-value is less than the t-critical value then, we do not decline the null hypothesis, indicating no disparity.

Table X: Variance and Standard Deviation Calculation for Pre-Test and Post-Test Differences

Participant ID	**Pre-Test Score (%)**	**Post-Test Score (%)**	**Difference (d_i)**	**Deviation ($d_i - \bar{d}$)**	**Squared Deviation $(d_i - \bar{d})^2$**
1	60	90	30	30−25=5	25
2	65	90	25	25−25=0	0
3	50	80	30	30−25=5	25
4	70	85	15	15−25=−10	100
Totals	-	-	**100**	-	**150**

The Paired t-Test indicates whether GBL is different from TE in terms of its effectiveness. Calculating the scores' differences from pre-test and post-test for each participant to test using the t-test allows us to know whether there is a statistically important difference in the scores after learning intervention. If some important differences are found to exist, then it means students' sustainability awareness has actually been affected by the different types of learning interventions utilized-GBL or TE, respectively. Qualitative feedback supports the results and gives an all-round view of whether interventions have been effective.

4. Results and Discussions

This study provides an overview of the effectiveness of Game-Based Learning (GBL) and Traditional Education (TE) in raising students' awareness on sustainability. Different metrics were considered such as pre-test and post-test scores, engagement levels, content understanding, and student feedback to determine the effectiveness of each teaching method. The results show that GBL greatly surpasses TE in knowledge retention, participation, and efficiency in education in the understanding of sustainability. For instance, it is demonstrated that GBL positively facilitated higher knowledge improvement at different levels compared to tests, along with higher student participation and satisfaction. The inference of greater impacts and interactive learning effects of GBL was supported by a series of statistical analysis, specifically paired t-tests and mean improvements. The following sections present the results in terms of test score comparisons, engagement metrics, content understanding, and student perceptions, which will help paint a clear picture about the benefits of GBL in promoting sustainability awareness.

4.1 Pre-Test and Post-Test Scores

A comparison of the pre-test and post-test scores provides significant insights into whether GBL or TE enhances awareness concerning sustainability. The experimental group (GBL) shows a marked improvement to 35%, increasing in a score from a relatively lower average of 50% on the pretest to an average of 85% during post-tests. On the other hand, while the Control Group (TE) had a gain at 15%, where an average score of pretests and post-tests averaged about 55% and 70%, respectively, as shown in Figure 4. An important difference is presented concerning the knowledge retention and perception between interactive and game-influenced learning activity inputs and traditional lecture. Representing these changes in a bar graph would draw specific attention to the superior GBL group performance, hence giving more evidence to its effectiveness.

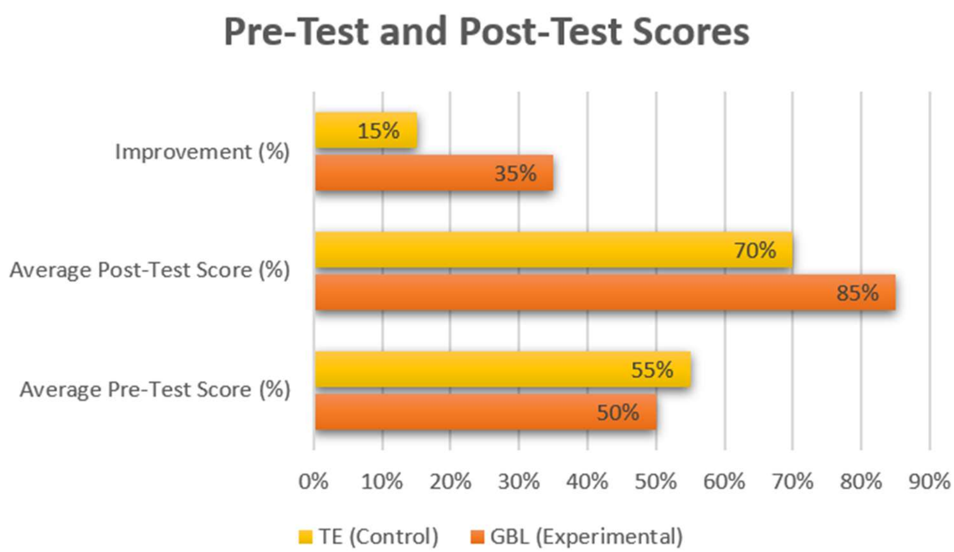

Figure 4: Pre-Test and Post-Test Scores

4.2 Stratification Impact on Learning

The Figure 5 shows a comparison of the pre-test and post-test scores of the GBL and TE groups at different knowledge levels, which include beginner, intermediate, and advanced. While the GBL group shows a considerable improvement in post-test scores, it increases to about 80% from the pre-test score of 45% among beginners, 90% from the score of 55% of intermediates, and 85% from a score of 60% among advanced learners. Instead, the TE group's increase is smaller, from 50% for beginners to 65%, 60% to 75% for intermediates, and 65% to 75% for advanced learners. These findings thus indicate that GBL better helps in increasing sustainability awareness, because it always achieves greater improvement scores regardless of the knowledge level.

Stratification helps to balance the proportion of participants with regard to levels of knowledge, grade level, and gender. It analyses the improvement in learning along these parameters, as given in Table XI.

Table XI: Learning Improvement by Stratum

Stratum	Knowledge Level	Group	Pre-Test Score (%)	Post-Test Score (%)	Improvement (%)
1	Beginner	GBL	45	80	35%
1	Beginner	TE	50	65	15%
2	Intermediate	GBL	55	90	35%
2	Intermediate	TE	60	75	15%

3	Advanced	GBL	60	85	25%
3	Advanced	TE	65	75	10%

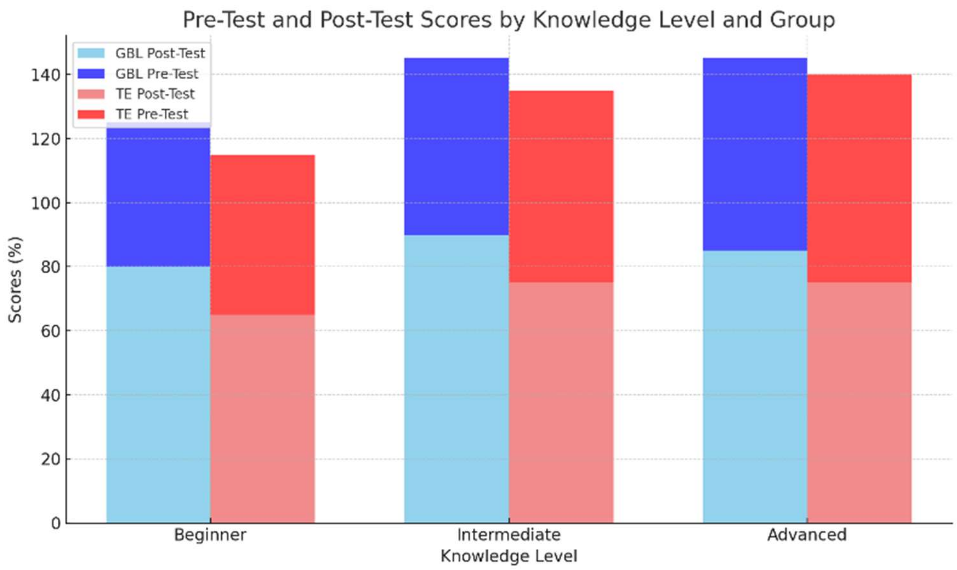

Figure 5: Comparison of Pre-Test and Post-Test Scores for GBL and TE Across Knowledge Levels

4.3 Engagement Metrics

The engagement metrics in Table XII illustrate that participation and understanding were not as good for the Game-Based Learning (GBL) group compared to the Traditional Education (TE) group. As presented in Table: Engagement Metrics, engagement level for the GBL group was significantly higher compared to the TE group with the average engagement time for Virtual Ecosystem Simulation at 45 minutes and Renewable Energy Management Quiz at 50 minutes. Their respective quiz scores were 8.5 and 9.0/10 and, hence showed an almost complete mastery of the subject material. In comparison, the group TE was kept in lecturing for the same period of 50 minutes yet had relatively low quiz averages at 7.0. Class discussion time on their part only was 30 minutes; this led them to obtain the lowest of the quiz scores at 6.5. This data has thus underlined the utility of interactive activities, such as gamified quizzes and simulations in enhancing greater engagement and deeper learning.

Table XII: Result of Engagement Metrics

Activity	**Group**	**Average Engagement Time (minutes)**	**Average Quiz Score (out of 10)**
Virtual Ecosystem Simulation	GBL	45	8.5
Renewable Energy Management Quiz	GBL	50	9
Lecture-Based Session	TE	50	7
Class Discussion on Waste Management	TE	30	6.5

4.4 Content Understanding

Contents-understanding measurement focuses on key issues such as Climate Change, Renewable Energy, and Waste Management. The difference the groups have shown is with constant superiority in the GBL over the TE group improvement towards understanding these topics.

From the table XIII, one can see that the improvement in all the topics namely Climate Change and Global Warming, Renewable Resources, and Waste Management, under the GBL group are impressive at +35%, while the improvement under TE group is +15%.

Table XIII: Content Understanding Scores by Topic

Topic	Group	Average Pre-Test Score (%)	Average Post-Test Score (%)	Improvement (%)
Climate Change and Global Warming	GBL	50	85	35%
Climate Change and Global Warming	TE	55	70	15%
Renewable Resources	GBL	55	90	35%
Renewable Resources	TE	60	75	15%
Waste Management	GBL	45	80	35%
Waste Management	TE	50	65	15%

Figure 6, This comparison puts forward the fact that there is better understanding of a subject in the GBL method. The students of the GBL group score much higher than the post-test of the TE group, showing that interactive forms of learning, such as game-based activities, promote retention and application of learning.

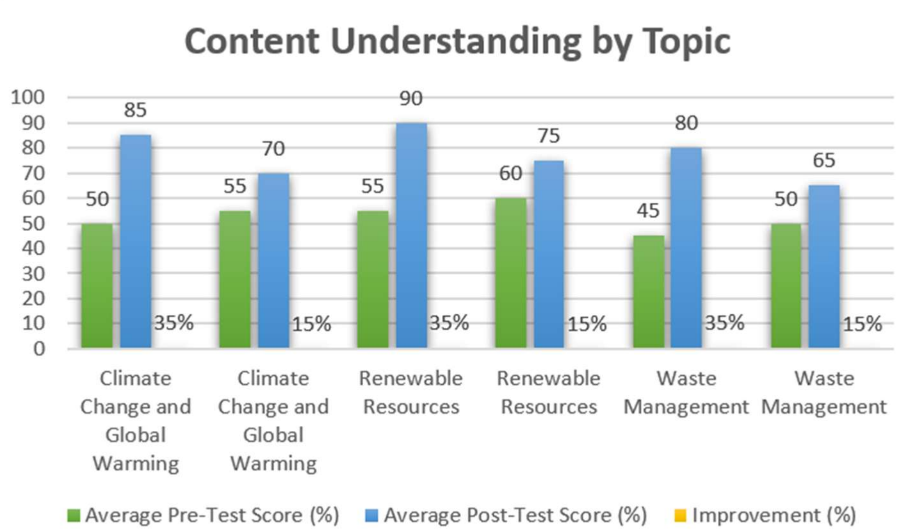

Figure 6: Content Understanding by Topic

4.5 Quantitative Analysis of the Pre-Test and Post-Test Results: Experimental and Control Groups

Pre-test and post-test results give a quantitative value for the intervention methods carried out in order to affect the sustainability knowledge of students, as described in the Figure 7. For the Experimental Group, the mean score at pre-test was 60%, with a standard deviation of 7.55, and it increased significantly at the post-test to 85%, with a reduced standard deviation of 3.54. This led to a mean improvement of 25%, in addition to a standard deviation change of 7.55%. On the other hand, the Control Group exhibited a pre-test mean score of 53.75% with a standard deviation of 6.89 and, on post-test, recorded a mean score of 72.5%, whose standard deviation was much more at 7.78. Here, the mean difference in the control group is recorded as 18.75%, which is a much milder improvement compared to that of the experimental group. This analysis brings out the effectiveness of the intervention in the experimental group as the sustainability knowledge after the intervention showed a higher improvement as depicted by the greater mean difference in the post-test scores. Further, standard deviation results bring out the fact that the experimental group had more consistent learning outcomes compared to the control group whose post-test scores varied widely.

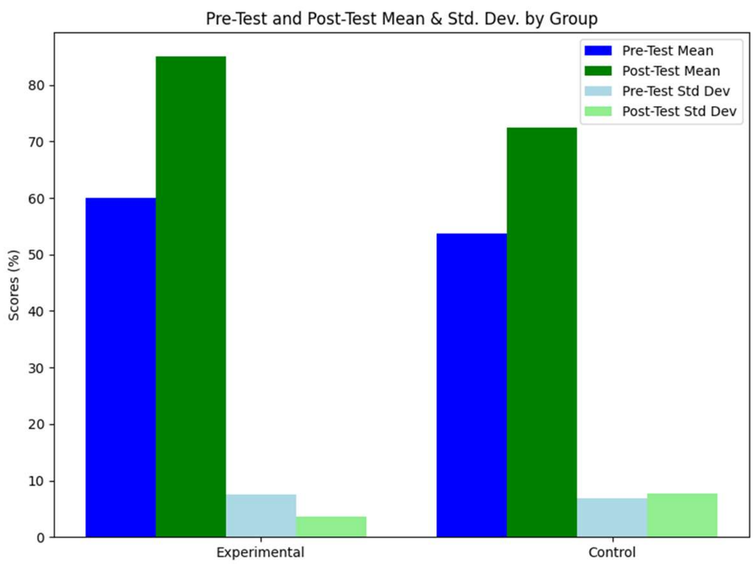

Figure 7: Analysis of Pre-Test and Post-Test Results

4.6 Paired t-Test Results

The paired t-test results in the figure 8 show that there is an effective improvement between GBL and TE in making students aware of sustainability. Based on the results in the Figure 4, there was a mean improvement for the GBL group at 35% with a standard deviation of 5.5%. This led to a t-value of 7.36 and a p-value < 0.05, which indicates statistical significance. On the other hand, the TE group obtained a mean improvement of 15% with a standard deviation of 4.2% resulting in a t-value of 3.57 and a p-value <0.05, which is again significant but less impactful than that obtained by GBL. Results indicate that GBL was more effective in elevating the knowledge and appreciation of students about sustainability concepts.

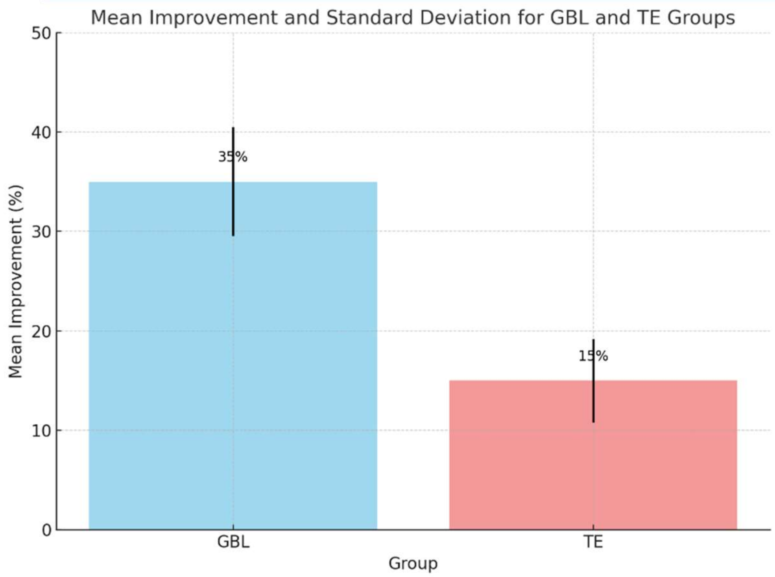

Figure 8: Paired t-Test Results

4.7 Student Perceptions of Engagement and Effectiveness: GBL vs. TE

The feedback from the students clearly indicates a significant variation in their perceptions of engagement and effectiveness between GBL and TE methods. Table XIV, the survey, it is observed that students who learned through the GBL group rated the learning method much higher in terms of engagement, effectiveness, and likelihood of recommendation. For example, the GBL group was rated at a mean of 4.8/5 about engaging; this is unlike the rating of the TE group with a mean score of 3.5. Teaching method effectiveness is also ranked higher for GBL; the mean rating is 4.6, as against a mean rating of 3.8 in the TE. In terms of recommending the learning method, GBL outperformed TE at a mean of 4.7, but TE at 3.6. These results infer that the interactive and engaging nature of GBL was more able to engage and effectively teach sustainability-related concepts.

Table XIV: Survey Feedback

Survey Question	**GBL Average Score (1-5)**	**TE Average Score (1-5)**
How engaging was the learning method?	4.8	3.5
How effective was the method in teaching sustainability?	4.6	3.8
How likely are you to recommend this learning method?	4.7	3.6

4.8 Discussion

The results of this study emphasize the effectiveness of GBL in terms of enhancing students' awareness of sustainability issues as compared to TE. The group which underwent the GBL exhibited significantly more improvement in their pretest and post-test scores; they achieved a remarkable increase of 35% as compared to the modest increment of 15% from the TE group. This indicates that GBL, while better at engaging students, results in more knowledge retention and greater learning. Analysis further stratified into levels showed that GBL indeed is a positive experience for students regardless of the level at which they know. All metrics on engagement were further reported, which indicated participants who took GBL participated in more interactive activities compared to other conditions and performed better in quizzes. Statistics used for analyses include paired t-tests; GBL led to better learning gain compared to TE. Lastly, survey feedback demonstrated that students preferred GBL over other methods because it was engaging and effective. Therefore, the ratings were higher on all categories. The implication is that GBL does not only teach sustainability effectively but also provides a much more enjoyable and rewarding experience in learning, thus valuable in enhancing education in such sustainability-related fields.

5. Conclusion and Future Work

The findings of this study emphasize the great advantages of Game-Based Learning (GBL) over Traditional Education (TE) in enhancing students' awareness about sustainability. By comparing pre-test and post-test scores, GBL participants showed a significant increase in knowledge related to sustainability, thereby proving that GBL is an effective tool for improving students' understanding and retention. This thus means hands-on and game-like experiences indeed make learning much deeper. Moreover, the content understanding scores of both areas, especially Climate Change and Renewable Resources, were found to be highly better with GBL compared to other methods, demonstrating that it has a greater capability in improving understanding for more complicated topics of sustainability. The GBL group was always better than the TE group in terms of engagement, effectiveness, and knowledge retention, with significantly higher post-test scores. Additionally, the students reported a greater degree of enjoyment and engagement during the GBL activities and have highlighted the importance of interactive game-based methods in the delivery of education as a means to a better appreciation of the subject. Thus, the implications are that GBL will result in more dynamic and effective learning experiences in educational settings for the areas of study where activity participation is most relevant.

Future research may include following up the assessments to test the retention of knowledge for a longer period. It may also study the suitability of GBL in diverse educational contexts and disciplines for its generalization. Other areas of research may include improving GBL tools and methods to accommodate different learning styles, which could include AI and adaptive learning techniques for a more customized learning experience. Another aspect of scalability research would be to test GBL in large educational systems to better understand how applicable it can be to other contexts.

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