Using a Digital Game to Provide Experiential Learning for Improved Understanding and ESD Skills in Science.

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Abstract.

Experiential learning has been proven to be effective in helping students gain practical and long-lasting understanding of science concepts. Recognizing this, an activity was done to assess the effectiveness of a digital game in providing experiential learning to foster students' improved understanding of environmental science concepts as well as enhanced ESD skills in science. In the activity, 9 pre-service teachers solved pollution and energy missions in a purposefully designed digital game to make a virtual city sustainable. The evaluation conducted before and after engaging with the game revealed a notable increase in mean performance, rising from 79.19% in the pre-test to 97.78% in the post-test at $t = -5.847$, with a corresponding calculated *p-value* of 0.0004 ($p<0.05$). The outcome underscored the efficacy of the game in fostering noticeable improvements in the academic performance of the participants. Furthermore, participants reported an engagement level of at least 7 on a scale of 1 to 10 showing that using the game not only captured the interest of the participants but also kept them actively engaged throughout the activity. This may imply that providing experiential learning through digital games offers a platform for; immersive learning, inquiry-based learning, critical thinking, and enhanced students' environmental consciousness which is critical in achieving SDGs.

Keywords: ESD Skills, experiential learning, SDGs, prospective science teachers, student's interest, and performance.

INTRODUCTION

In the face of rampant environmental sustainability challenges, Education for Sustainable Development (ESD) promises to equip students with relevant skills that promote sustainability by helping achieve the Sustainable Development Goals (SDGs). Both educators and governments emphasize the incorporation of ESD in education curricula. However, for science teachers, the main challenge is how to provide valuable learning experiences that effectively promote scientific understanding as well as ESD skills, both of which are mostly abstract.

On the nature of science, Louca & Zacharia (2011) describe science as a complex, multifaceted activity that includes forming and justifying new knowledge to explain natural phenomena. Based on this, it is believed that students tend to learn better when they assume an active role in constructing their own knowledge through experiences and interpretation (Roschelle et al., 2001). With this background, experiential learning is critical in fostering students' ability to gather long-lasting practical knowledge and understanding of science.

In recent years, educators have been trying to find innovative ways of providing students with experiences through which they can learn. One of these innovative ways is the use of games in educational settings. Existing literature states that games offer engaging platforms for experiential learning (Arnab, 2014).

Furthermore, Plass et al. (2020) highlighted that game-based learning helps students (1) acquire new knowledge and skills about an important subject matter, (2) practice existing knowledge and skills, (3) develop learning and innovation skills, and/or (4) prepare for future learning. From the arguments made for the use of games in education, one is compelled to theorize that using games in science can yield remarkable results considering that science seems to be better learned when experience and active learning are employed.

Even though there has been extensive research on game-based learning and gamification in science education, there is a gap in research on game-based learning for environmental education and ESD skills in science.

To emphasize the need for environmental and ESD in science education, literature reports that since the dawn of industrialization, the world population has continued to increase exponentially entailing a corresponding rapid depletion of natural resources such that scientists forecast that if measures are not taken, humanity will require an equivalent of three planets to satisfy the requirements for food, water, energy, and other natural resources by the year 2050 (Streilling et al., (2020); Goodland, (1995)).

Environmental education in science is fundamental in the attempt to address pressing global challenges, that range from, pollution, energy, diversity conservations, and many others. For instance, in describing pollution, Morelli (2011) states that humanity's inability to fit its activities in the patterns of nature, is changing planetary systems, and these changes are accompanied by life-threatening hazards from which there is no escape.

Furthermore, the reliance on non-renewable energy sources has exacerbated environmental degradation in both developing countries and more so in developed countries. To illustrate this, only 12.4 % of the 20,000,000 population of Malawi has access to electricity (JICA, 2022). With the remaining 87.6% solely depending on the environmentally damaging sources of energy.

Figure 1. Illegally produced Charcoal is commonly used as an energy source in Malawi. (Source: NYASA TIMES)

On the other hand, in Japan, despite a relatively larger percentage of the population having access to electricity, fossil fuels still account for 88% of Japan's total energy supply (IEA, 2021). It is even more alarming on the global energy stage where studies have revealed that fossils constitute 81% of all the energy produced (IEA, 2021).

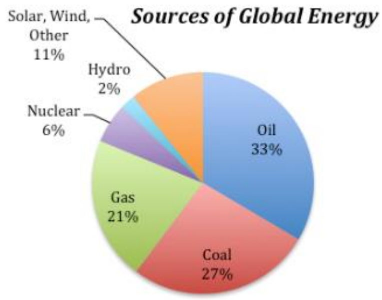


Figure 2. Percentage contribution of different sources to world energy. (Source: IEA, David Bice)

From these revelations, it is evident that environmental degradation because of pollution and unsustainable energy sources are sectors that need urgent and vigorous action. Therefore, this study was designed around fostering game-based learning for both improved scientific understanding and enhancement of ESD skills in science by focussing on pollution and energy sources. Specifically, this study sought answers to the following questions:

1. What impact will the game have on participants' understanding of pollution and energy sources?
2. Can games be effectively used to promote ESD skills in science education?
3. To what extent will the participants be engaged in the activity?
4. What impact will interacting with the game have on participants’ perspectives on the use of games as a teaching tool in the future?

RESEARCH METHOD

A systematic and structured experimental approach was adopted to draw meaningful conclusions regarding the educational efficacy of using a game in environmental education science. This approach was suitable for this study based on arguments by multiple researchers who argue that when used thoughtfully in education, games may contribute to active learning due to their interactive and engaging nature. (Gee, (2008); Hamari et al., (2014)). As such, to ascertain the game's impact on students' performance and engagement, assessments were administered through Google Forms before and after the game intervention.

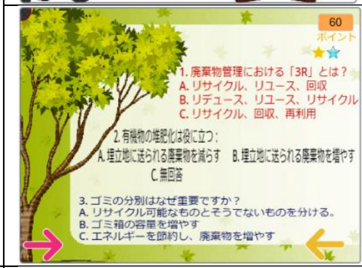
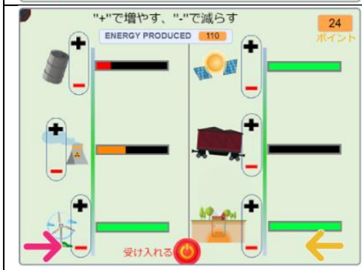
A digital environmental educational game simulating a virtual city was developed in *Scratch* which is a visual programming language developed by the MIT Media Lab. The game was designed to be platform-independent and accessible through standard web browsers without the need for additional installations on various devices including computers, smartphones, and tablets.

In the game, the task was for participants to make the city environmentally sustainable by solving pollution and energy challenges faced by the city. To successfully play the game, participants used their: (i) Understanding of science concepts, (ii) Decision-making skills, and (iii) Collaboration skills. Upon successful completion of the missions in the game, participants would obtain 3 in-game stars and win the game.

To foster learning, educational concepts were incorporated into the game scenes by integrating learning points as shown below.

Table 1. Game scenes and learning points.

<table>
<tr><th>MISSION</th><th>GAME SCENE</th><th>TASK</th><th>INTERACTIVE ELEMENTS</th><th>LEARNING POINT</th></tr>
<tr><td rowspan="2">Pollution</td><td>
</td><td>Identify sources of pollution.</td><td>Participants clicked on the elements they understood as sources of pollution.</td><td>Understanding of sources of various types of pollution</td></tr>
<tr><td>
</td><td>Answer a quiz on pollution.</td><td>Participants clicked on the answer they deemed correct.</td><td>Understanding of effects of pollution.</td></tr>
</table>

		Sort household garbage.	Participants chose whether to sort the garbage off or not.	Participants' decision-making skills.
		Answer a quiz on pollution.	Participants clicked on the answer they deemed correct.	Understanding of the importance of sorting garbage about recycling.
		Identify renewable energy sources.	Participants clicked on the icons representing renewable energy sources.	Understanding of renewable and non-renewable energy sources.
Energy		Rank and regulate energy sources.	Participant ranked the energy sources based on their impact on the environment. Participants decided which and to what extent to utilize the energy sources.	Understanding of environmental impacts of different energy sources.
		Control the total energy received by the city.	Participants regulate how much total energy to be received by the city.	Decision-making skills.

Though the game's educational content focused on Junior high school science environmental education, first-year pre-service science teachers at a Japanese public university participated in the activity. This allowed for the collection of data both on the effectiveness of the game as a teaching tool as well as the pre-service science teachers' attitudes on using games when teaching science. For objectivity, participants used either numbers or letters as their identity throughout the activity. Participants were partnered by an online random-pair generator accessed at: https://randomgenerate.io/random-pair-generator to promote participant collaboration.

Before game-play, participants ranked energy sources from best to worst based on their environmental impact. Participants used this information to solve the energy mission in the game. During game-play, for each unsuccessful run, participants were able to reset the game multiple times until the mission was satisfactorily completed.

After the collection of pre-test and post-test responses, descriptive statistics (means and standard deviations), were used to summarize participants' performance. A Paired sample t-test was used to assess the significance of the observed difference between the pre-test and the post-test scores. Furthermore, determinant questions on both the pre-test and the post-test were visualized using charts and analysed to determine if there was a shift in the participants' perceptions after interacting with the game. Attitude and engagement responses were also analysed to assess the game's impact on participants' attitudes toward the use of games when teaching science.

RESULTS AND DISCUSSION

A face-value comparison of the means from the pre-test and the post-test showed an increase in the knowledge of the participants in environmental-related concepts from 76.19% to 97.78%. A decrease in the standard deviation from 10.10 on the pre-test to 6.67 on the post-test was also observed. This notable enhancement in participants' performance was directly attributed to the efficacy of the game. This outcome was in line with a finding by Chen, et al., (2019) that games in education, contribute to significantly better students' performance.

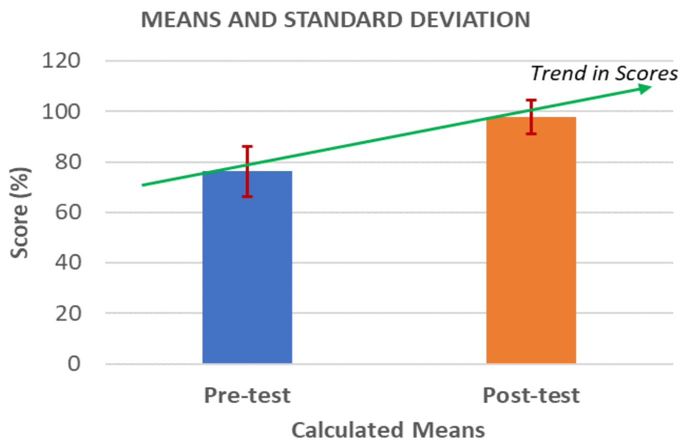


Figure 3. Pre-test and post-test mean comparison.

A paired-sample t-test attested to the statistical significance of the difference between pre-test and post-test scores at t= -5.847 and a calculated *p-value* of (t (8) = 0.0004, $p < 0.05$), an outcome that was consistent with our prediction.

Furthermore, an assessment of determinant questions on both the pre-test and the post-test showed an increase in correct responses from 22.2% on the pre-test to 88.9% on the post-test revealing a shift in students' conceptions after interacting with the game.

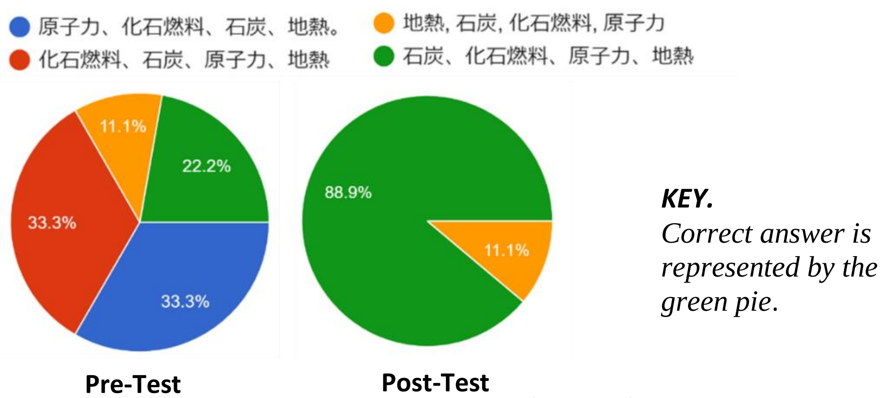


Figure 4. Scores on determinant questions on Pre-test and Post-student.

This is further supported by an observation by Wichaidit & Sumida (2023) that game-based learning fosters cognitive and intentional conceptual change, during which students extend their conceptions.

Before interacting with the game, all participants supported the use of games in teaching science while in the post-test, about 66.7% of the participants supported the use of games in teaching science.

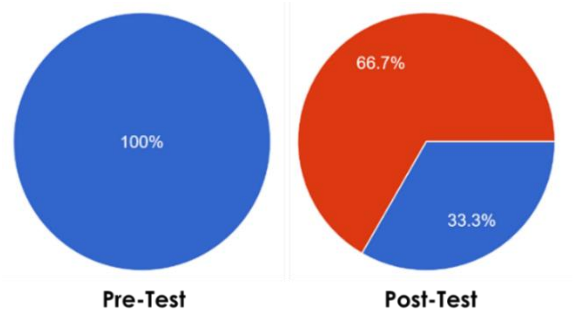


Figure 5. Pre-service Teachers' attitude towards using games in teaching.

The shift in participants' attitudes was incongruent with the predictions and several factors including participants' game preferences might have contributed to this shift. This is pointed out by Van Gaalen, (2022) who states that students' game preferences must be considered when designing game-based learning since not every game-based learning strategy fits all students.

A reported 7 on a scale of 1 to 10 level of engagement, revealed the game's ability to intrigue and capture participants' interest throughout the activity.

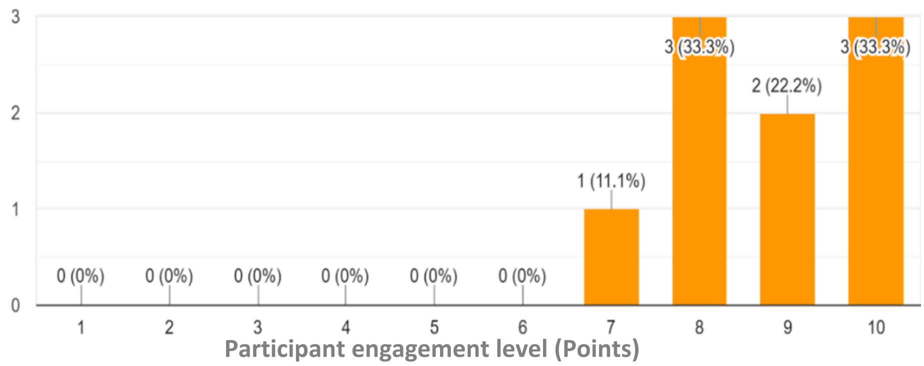


Figure 6.Students' engagement level.

This outcome is further supported by results from studies by multiple researchers who reported that using games in education keeps students engaged (Gee, 2008; Deterding et al., (2011); Hamari et al., (2014); Glover, (2013)).

Though a remarkable body of knowledge was generated by this study, it wasn't without limitations which may undermine the generalisability of its findings. Firstly, the study was conducted with a group of only 9 participants, and this may impact the generalizability of the findings to a broader population. As suggested by Hedges & Rhoads (2009), for a study to have a general inference on the population, the sample size must be a true representation of the population size. Therefore, future research could benefit from conducting a similar study but with a larger population sample. Secondly, the researcher's inability to speak Japanese might have hindered the smooth exchange. In future research, the use of a real-time translation tool may help foster smooth communication for thorough explanations of concepts about the study where necessary.

CONCLUSION

Overall results revealed that the game served as an effective tool in; capturing the interest of the students, promoting students' participation, enhancing understanding of relatively abstract concepts, actively engaging the students' skills in problem solving as well as calling students to action collaboratively work towards environmental sustainability. This may imply that using such an innovative tool in the teaching and learning of science can promote immersive and inquiry-based learning, and critical thinking as well as promote students' environmental consciousness for SDGs achievement. Plass et al. (2020); and Prensky (2001) agree with these findings by their stance that integrating games into science education provides an interactive and dynamic approach to learning. These attributes of the game, align with the guidelines of ESD towards attaining the 17 SDG goals which are (i). To promote concrete actions through the development of interest, understanding, attitude, and ability to solve problems. (ii). To have a participatory approach that emphasizes experiences, common sensation, inquiry, and practice, and (iii). To withdraw the willing action of learners during activities (Kadoya & Goto, 2013). Therefore, teachers must explore ways to effectively incorporate games and other innovative tools into their teaching arsenal to foster students' experiential learning in science.

Acknowledgements.

I am grateful to the respondents for availing themselves during data collection.

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Appendix 1: Educational Game Pre-Test.

科学教育におけるゲーミフィケーション教育アプローチ：環境教育における学習者の関与と成績への影響の評価。（事前テスト）

名前やメールアドレスを入力しないでください。データ処理を容易にするために、演習の最初に与えられたコードを使用してください。

導入

ゲーミフィケーションとは、ゲームデザイン要素やゲームの原則をゲーム以外の物事に応用する散る国です。この活動は、中学校の科学の環境教育における教育ツールとしてのゲームの使用に関するデータ収集を行っています。

パート A：参加者の情報

参加者番号：

年齢:　男　　女

学術専攻:________________________

パート B：知識評価

1. 大気汚染の主な原因は？
   a. 自動車排出ガス　　c. 工業排出ガス
   b. 火山噴火　　d. 上記すべて
2. 廃棄物管理における "3R "とは何を意味するのか？
   a. リサイクル、リユース、リカバー　　c. リデュース、リユース、リサイクル
   b. リサイクル、リカバー、リバーパス　　d. リデュース、リサイクル、リカバー
3. 埋立地の廃棄物を減らすための最も環境に優しい方法とは？
   a. 堆肥化　　b. 燃えるゴミ　　c. 河川への廃棄物投棄
4. 廃棄物の分別が重要だと思うのはなぜですか？____________________________________
5. 再生可能エネルギー源を 2 つ挙げよ:____
6. 化石燃料の燃焼によって生じる副産物のうち、気候変動の原因となるものはどれか？
   a. 酸素　　c. 二酸化炭素
   b. 窒素　　d. 硫化水素
7. 以下の選択肢のうち、環境負荷の点で最も悪いものから最も悪いものまで、さまざまなエネルギー源を正しい順番で示したものはどれか
   a. 原子力、化石燃料、石炭、地熱。　　c. 地熱, 石炭, 化石燃料, 原子力
   b. 化石燃料、石炭、原子力、地熱　　c. 石炭、化石燃料、原子力、地熱

パート 3：態度評価

1. 環境問題について学ぶことへの関心度をお答えください。

   1　　2　　3　　4　　5
   興味なし　　　　高い関心
2. あなたは以前、教育現場でゲーミフィケーション学習法に取り組んだことがありますか？
   a. はい　　b. いいえ
3. 将来の教師として、科学における環境問題を教える際にゲームを使う、あるいは使うことを薦めますか？
   a. はい　　b. いいえ

Appendix 2: Educational Game Post-Test.

科学教育におけるゲーミフィケーション教育アプローチ：環境教育における学習者の関与と成績への影響の評価。(事後テスト)

名前やメールアドレスを入力しないでください。データ処理を容易にするために、演習の最初に与えられたコードを使用してください。

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パート A：参加者の情報

参加者番号:____________________

パート B：知識評価

1. 再生可能なエネルギー源を使用することで、非再生可能なエネルギー源と比較して環境への影響は常に低くなる

   a. 真の　　　　b. 偽

2. 再生可能エネルギー源を 2 つ挙げてください:____

3. 以下の選択肢のうち、環境負荷の点で最も悪いものから最も悪いものまで、さまざまなエネルギー源を正しい順番で示したものはどれか。

   a. 原子力、化石燃料、石炭、地熱　　　　b. 地熱, 石炭, 化石燃料, 原子力
   b. 化石燃料、石炭、原子力、地熱　　　　d. 石炭、化石燃料、原子力、地熱

4. 炭素排出による気候変動に寄与するエネルギー源はどれか？

   a. 太陽エネルギー　　　　c. 化石燃料
   b. 原子力　　　　d. 水力エネルギー

5. 大気汚染を減らすために最も効果的なのはどの行動か？

   a. プラスチック包装の製品を買う　b. ビニール袋の代わりに紙袋を使う　c. 落ち葉やゴミを燃やす

パート 3： 態度評価

1. 環境教育ゲームをすることで、環境問題に対する見方が変わった。

   1　　2　　3　　4　　5
   強く同意する　　　　強く反対

2. ゲームをプレーしている間、どの程度関与していると感じましたか？

   1　2　3　4　5　6　7　8　9　10
   まったく関与していない　　　　非常に熱心

3. 環境問題に対する意思決定の影響について理解を深める上で、ゲームの効果を 1～5 の 5 段階で評価してください。

   1　　2　　3　　4　　5
   効果なし　　　　非常に効果的

4. 将来の教師として、科学における環境問題を教える際にゲームを使う、あるいは使うことを薦めますか？

   a. いいえ　　　　b. はい

5. 科学の授業でゲーミフィケーションを教材として使う場合のアドバイスは？