Serious(Game)ly Sustainable: Sustainability Concepts through an Educational Video Game

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Talha Bin Asad is a fourth year PhD student in the Department of Engineering Education at Virginia Tech. He completed his bachelors in mechatronics engineering at the University of Engineering and Technology, Pakistan, and his master's degree in mechanical engineering at Shanghai Jiao Tong University in Shanghai, China. As a research assistant in the robotics and automation lab during his masters, he discovered an aptitude for mechanical design and built a single-handed, 6-axis robotic joystick controller. Currently, Talha's PhD dissertation work involves the role of educational board games in developing undergraduate students understanding of empathy and sustainable decision-making. In the future, he is hoping to continue his research and develop a video game that teaches industrial sustainability concepts such as circular economy to undergraduate engineering students.

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Abstract

'Sustainability' refers to a balance between resource consumption and environmental protection with aims of securing the future. As such, it encompasses multiple fields and concepts. One such concept is circular economy (CE), which is widely used in industry to aid sustainable decision-making from a practical standpoint. CE revolves around the process of 'resource sharing' among various industrial sectors. It simulates how industries can share their waste products with each other, hence creating a system with minimal waste products through complex industrial waste treatment processes. This a) helps increase profits by reducing the cost of raw materials; b) reduces overconsumption of resources obtained through practices detrimental to the environment; c) minimizes pollution; and d) helps secure a sustainable future for life on planet Earth. Overall, this is a win-win scenario for industry owners as well as for environmental sustainability, making a strong argument to include the learning of circular economy concepts in sustainability education.

Within the context of engineering education, circular economy concepts are taught via various instructional methods, ranging from class lectures to field trips and analyses. One of the challenges with traditional methods however, may include student learning motivation in classrooms. As such, an engaging class activity for certain course modules such as CE may include educational board games.

Video games were found to be an effective learning mode of instruction in STEM education [1], [2], offering an alternative to traditional lectures. Moreover, video games help with student motivation to learn as well, as argued by Molins [3] and Ebrahimzadeh et al [4]. Unlike passive instruction, games simulate real-world processes in simplified form, helping students grasp complex concepts through play. Additionally, they let students apply theory to practice in a risk-free, interactive environment, which helps with learning.

Educational video games have already been introduced in some engineering courses [5], [6], [7], [8] as part of class activities to cover certain topics in engineering courses. This current work-in-progress paper discusses the process of developing a video game to expose undergraduate engineering students to the impacts of sustainability and introduce students to basic concepts of CE. The game features a solo player role-playing as an engineer stuck on an island with their broken rocketship, trying to escape by rebuilding the ship. There are products and materials scattered on the island that the player can find and utilize, but certain waste products such as organic waste, fabric scraps, ash/sludge, etc. are generated alongside the processes required for rebuilding, requiring the player to make critical decisions surrounding scarcity of resources and waste management. The player must decide how to manage these waste products by either processing them (recycle, reuse, biodegrade, repurpose, refurbish), or eventually taking a substantial penalty (such as destruction of the ship amidst the escape). The game explores several other in-game mechanics such as resharing processed waste materials and repurposed products within different sections of the ship to impart basic concepts of CE to students. The aim of this project is to ensure that the game is fun to play and generates interest in CE for engineering students.

Introduction

One of the earliest mentions of the word ‘sustainability’ was in the 1970s, when it was stated in a report that humans’ way of life with industrial expansion, population growth, ecological disruption, and resource depletion was ‘not sustainable’ [9]. As such, ‘sustainable development’ as a term was introduced by the Brundtland Commission in 1987 [10], defining sustainable development as “providing for human needs without compromising the ability of future generations to meet their needs” [11], [12]. To understand what sustainability means, we must look at the different domains and contexts of sustainability, including economic aspects, sociological and ethical perspectives, and biological and engineering implications [13]. Practical measures to incorporate sustainability in engineering include industries’ investment into making their products sustainable [14], [15], [16], [17], managing high quality control, paying attention toward biodegrading and recycling of materials [18], conserving raw material and energy sources [10], and chemical and plastic waste management [19].

Particularly in the context of engineering education, the learning objectives and goals for engineering students have historically been aimed toward improving technical skills [20], [21]. However, in recent years engineering programs have incorporated social responsibility and sustainable development as additionally required objectives [22], [23]. Transferring knowledge, awareness, and skills to students requires instructional methods that are effective, and there have been a number of teaching and learning styles historically implemented in engineering education instruction [24]. As suggested by Felder and Silverman, ‘deduction’ is used in traditional college teaching approaches, which prioritizes learning the basics of a subject first, followed by its field applications or relevant real-world problems. On the other hand, an ‘induction’ approach starts by presenting a real-world scenario or problem and tries to learn fundamentals while solving it, just as in problem-based learning setting [24]. In addition, Felder et al. (2000) pointed out that illustrating and demonstrating course material visually in the form of pictures, schematics, and computer simulations can stimulate learning [25], which is the case in game-based learning. Considering these learning and teaching styles, game-based learning has been previously identified as suitable for engineering education [6], [26], [27].

In this proposed study, we aim to utilize an educational computer video game designed to increase student knowledge of sustainability (named ‘SusLyfe’) as an intervention to compare whether a game-based learning tool is more effective at inculcating concepts and knowledge of sustainability in engineering students as compared to traditional methods alone.

Literature Review

Application of Sustainability in Engineering

Over the course of industrialization, humans have largely contributed to manifest changes in the natural habitats, environments, and systems of the planet [28]. These changes have had a significantly disadvantageous impact on climate and other factors affecting human life and habitation, which has led to an increasing call for better environmental policies [29]. As industrialization and globalization [30], [31] are one of the central issues underpinning these changes, sustainable engineering practices become imperative to ameliorating their negative consequences [32]. Therefore, sustainability needs to not only be incorporated into engineering education but also developed continuously as a process demanding long-term investments and guided research from global academic communities.

Incorporating Sustainability in Engineering Education

Current literature reveals that the role of sustainability in engineering education can be realized through the use of Education for Sustainable Development (ESD) principles, as stated by Guerra [33]. However, research on how ESD can be integrated into the engineering curriculum is still ongoing [34], [35], [36] (Segalàs, 2009; Hopkinson & James, 2010; Shahidul, 2020). Guerra points out that although sustainability awareness is now part of engineering courses, the practical incorporation of sustainability principles calls for an institutional transformation at different levels. As such, multidisciplinary teamwork, systems thinking, lifelong learning, adaptability and flexibility are some of the sustainability traits that need to be incorporated in engineering students to realize the vision of ESD [33].

Engineering educators too have the responsibility to break the vague qualitative term of 'sustainability' into customized, well-defined quantitative procedures that enable engineering students to apply sustainability principles to their designs and projects [28]. Teaching courses with sustainable engineering principles involves challenges in terms of application of appropriate rigor [37] in pedagogy and assessment of student learning outcomes [38], and determination of sustainability as a specialty course versus as a part of other disciplines [39], [40].

Gamification

A game can be defined as an environment in which players engage in abstract challenges [41]. As an increasingly popular source of entertainment, games are here to stay [42]. As such, it follows that the gamification of learning is an emerging instructional approach [41]. Kapp argues that gamification has wrongly been attributed to its reward system only, which limits its potential. Foundational elements of gamification such as storytelling aspect, character visualization, engagement of players, and problem-solving are much more important, and thus have far greater potential to lead to better learning [41]. As [43] suggest, in the educational context, one of the ways to retain attention and engagement of students can be through games and gamification.

Application of Game-based Learning to Sustainability

Game-based pedagogical strategies that facilitate student learning are being increasingly implemented in educational settings [44], [45]. Therefore, games offer an opportunity to incorporate sustainability concepts into education for better student learning, such as interdisciplinary aspects mentioned by [46]. Suzuki and colleagues designed and implemented a fully game-based class which incorporates a board game called the "Power Generation Mix". The purpose of the board game was to define the criteria of a power supply system to a city through various methods including coal-based power plants, nuclear, and renewable sources, and to calculate the final scores based on total costs, carbon emissions, and energy policy tradeoffs as the criteria [46]. In their efforts to perform well on the game, students learned not only the impact of sustainability but also ways to resolve power issues by creating a balance between high costs and high carbon emissions while generating ample power supplies for the city. This is an excellent example of simulating real-world problems and teaching sustainability concepts through game-based learning.

Practical Considerations for Introducing Game-Based Learning

Bringing game-based learning to engineering classrooms requires considerations about the various *affordances* linked with this process, one of which is the financial affordability of designing games for students and developing a game-based curriculum. In their study about the design of augmented reality (AR) based games, Alternate Reality Games (ARGs), and 3-dimensional computer games using low-cost tools and technologies, Whitton [47] states that such games do not require high technical expertise or production values to build. This makes game based learning an affordable way to engage students in learning and problem solving. As stated by de Carvalho [26], accessing whether students learned what they were supposed to learn by using a certain educational tool is not simple. As such, game-based learning stimulates students' mind and body, and helps them develop practical skills by involving them in decision-making, prioritization, and problem-solving activities in games [26]. Successful instances of applying game-based learning to engineering education contexts involve studies such as use of an online game to make complex theoretical knowledge of civil engineering more approachable [48], assessment of efficacy of an interactive tool for learning surgical management algorithms [49], student competency development in building services education by simulating work life through games [50], and defining a game-based framework for Science, Technology, Engineering, and Mathematics (STEM) learning environments for various types of learners [51]. Such applications suggest that game-based learning is an accessible way towards student learning.

Given that game-based learning is increasingly applied to various educational contexts, including engineering education, it can also be used to enhance student learning about sustainability. Finding out whether student learning outcomes pertaining to sustainability can be improved through game-based learning has not been previously investigated in engineering disciplines. Therefore, we aim to address this gap by implementing a game-based intervention in an engineering course and accessing relevant student outcomes. In the following sections, we discuss the study settings, research methods and proposed analysis. We will start with the study's theoretical framework to provide the rationale for the choice of research methodology and plan for interpretation of findings.

Theoretical Perspectives

Generative Learning Theory

Wittrock [52] suggests that the human brain is capable of learning concepts in areas such as mathematics, reading comprehension, and science. It actively constructs meaning by building relations between existing knowledge and new information [52], [53]. In that regard, generative learning theory posits that learning involves active cognitive engagement where learners integrate new information with existing knowledge, thereby creating meaningful connections. This theory connects with game-based learning (GBL) in a number of ways. This subsection briefly considers the perspectives of using generative learning theory to explain the 'why' behind understanding of sustainability concepts among undergraduate engineering students via game-based learning.

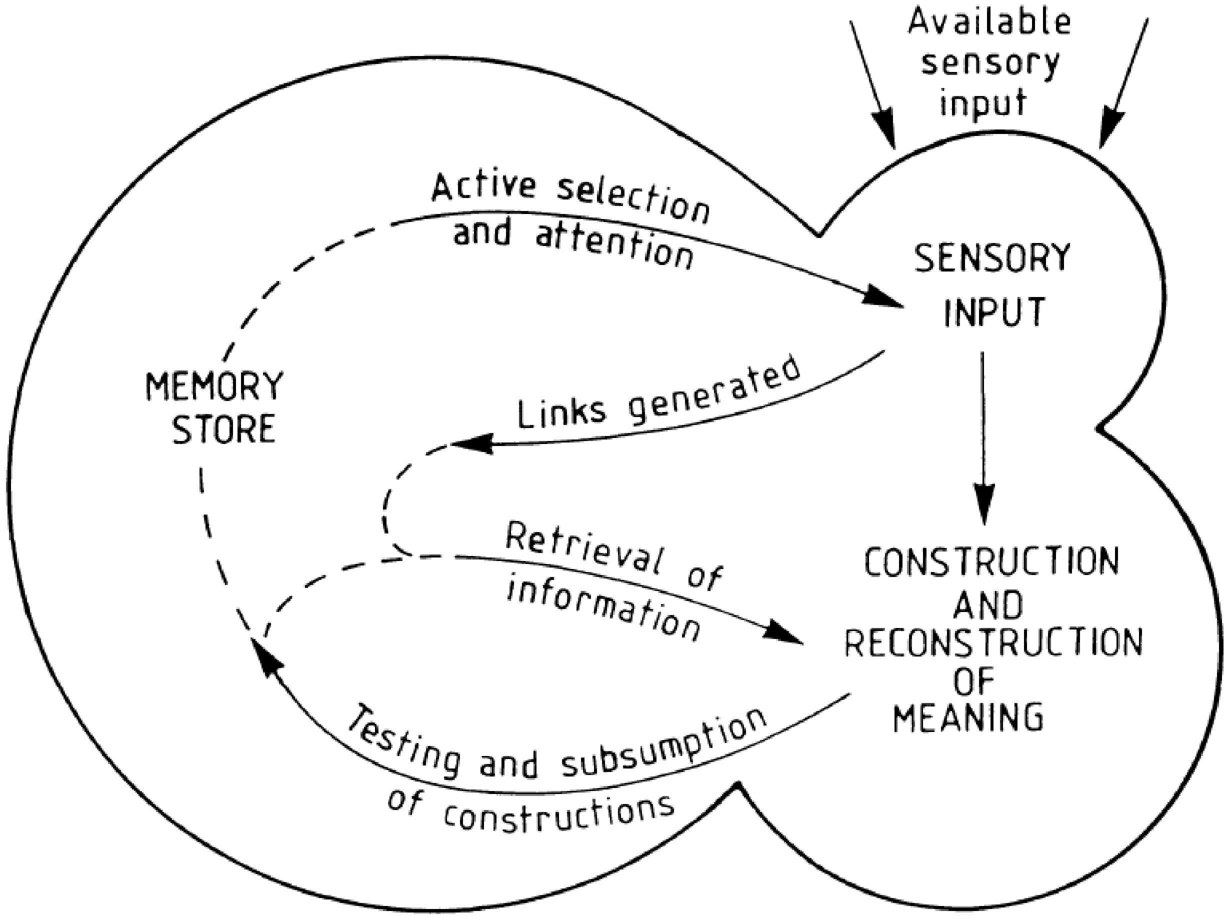

Figure 1: Schematic representation of generative learning (image taken from Osborne & Wittrock, 1985)

Generative learning theory, first articulated by Merlin Wittrock , revolves around the idea that learners actively generate knowledge through cognitive engagement with content [52]. This process involves generating inferences, hypothesizing, and making connections between new information and prior knowledge. Generative learning theory has applications in education, including in instructional design [54], where it can help students involved in activities that promote active engagement, such as collaborative projects and problem-solving tasks. Furthermore, use of visual tools such as diagrams and information tables can help learners organize and generate connections between concepts and encourage learners to set goals, monitor their progress, and reflect on their understanding. Generative learning builds on ideas from cognitive psychology and is closely related to theories like cognitive constructivism [55], [56] and social constructivism [57], [58].

In the context of GBL, this theory suggests that when students are placed in a simulated environment where they can manipulate objects, interact with environment actors, and see the outcomes of their actions, they are likely to engage more deeply with the material, thus constructing meaning (as shown in Figure 1) in a coherent way that leads to an overall better understanding and retention of sustainability concepts.

Game-Based Learning as a Stimulas for Generative Learning

Game-based learning offers a rich platform for applying generative learning principles. Games inherently require players to make decisions, solve problems, and think critically — activities that align with the cognitive processes promoted by generative learning theory. In engineering education, sustainability concepts can often seem abstract and disconnected from real-world applications [59], [60]. By presenting these concepts via diversified gaming levels and scenarios, students can see the immediate consequences of their decisions, leading them to make more informed choices. In a way, this stimulates real-world applications of the subject matter, which in the case of this research, is sustainability.

Cognitive Engagement in Game-Based Learning

The interactive nature of games stimulates cognitive engagement, a key component of generative learning. Games that are designed for educational purposes often incorporate elements that require students to analyze, evaluate, and synthesize information. For undergraduate engineering students, this could involve scenarios that mimic real-world engineering problems, requiring sustainable solutions. Through such gameplay, students receive information while also actively constructing new knowledge (as shown in Figure 1).

In a holistic sense, implementing a game into the traditional classrooms might facilitate the learning process of students. This study aims to utilize the generative learning concepts to test whether the students who are involved in game-based learning achieve better scores on class assessments, particularly in regard to sustainability-related modules. Incorporating generative learning theory into game-based learning environments may offer an applicable approach to teaching sustainability via a novel instructional method (on undergraduate level), which is the purpose of this study. Further information about the current development status of the particular game used in this study is provided later in the methods section.

Interest

Interest, as conceptualized within educational psychology, is a psychological state that enhances engagement, learning, and persistence in activities [61], [62]. It is characterized by increased attention and better performance in activities that capture one's affective and cognitive involvement. Interest can be quite useful in educational settings, particularly in enhancing students' motivation and engagement with the course material.

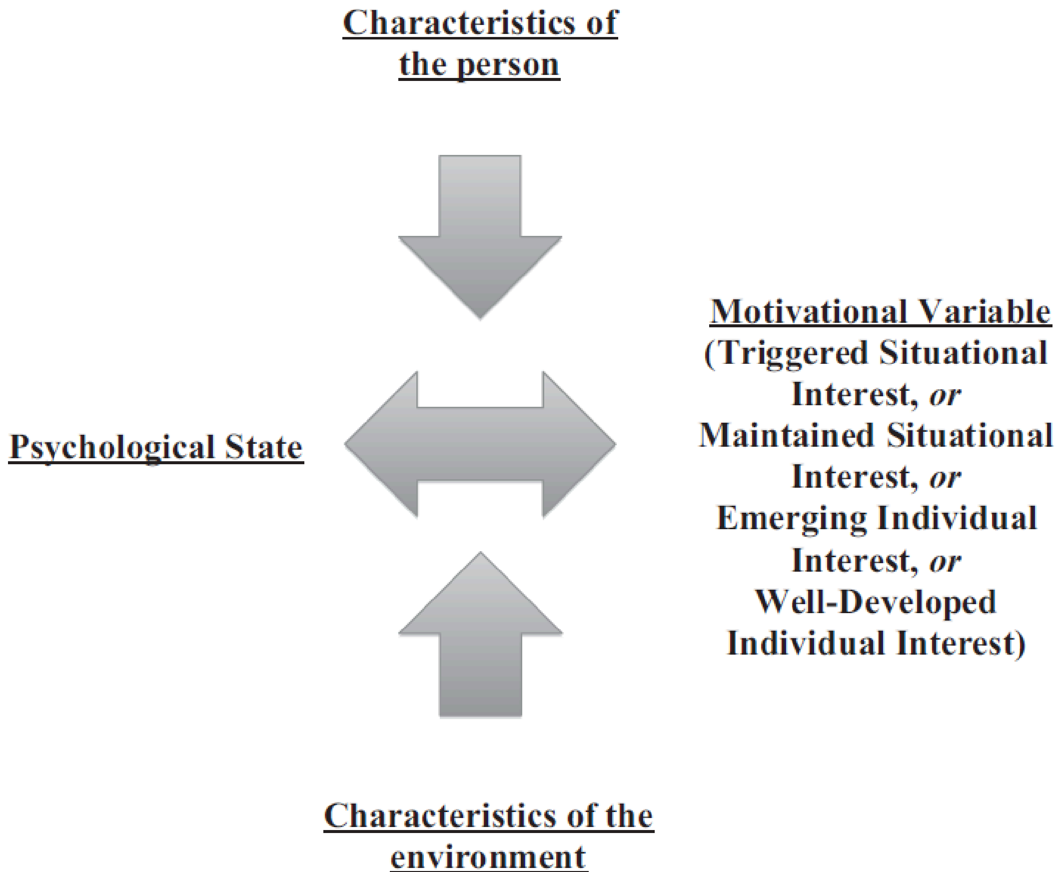

Figure 2: Dual Meaning of Interest: Psychological State & Motivational Variable (Taken from Renninger & Hidi, 2015)

Phases of Interest

According to Hidi's model, the development of interest is typically described through four phases [63], progressing from triggered situational interest to well-developed individual interest:

Triggered situational interest is categorized by short-term changes in cognitive and affective processing. This is categorized by a person experiencing an activity due to external factors, which may or may not lead to their persistence on that activity. *Maintained situational interest* is the next phase following the externally triggered situational interest, that results in focused attention to a particular class of content that recurs/sustains overtime. The person experiencing maintained situational interest is thought to engage in meaningful tasks that are externally supported. In some cases, this can lead to *emerging individual interest*, which is a relatively enduring predisposition to reengagement with a particular class of content overtime. A person experiencing individual interest has positive feelings toward the task at hand, and values the knowledge gained via this experience. Individual interest exhibits a change from externally supported to self-generated interest in learning. Then, the final phase of interest is *well-developed individual interest*. This is an enduring predisposition to seeking engagement with a particular class of content over time. It is characterized by a sustenance of long-term constructive and creative endeavors, and generation of more types and deeper levels of strategies of working with tasks.

As part of this study, I am interested in how undergraduate engineering students can be better motivated to engage with class material, as demonstrated practically in the MUSIC model of motivation [64], [65]. In that regard, Hidi's interest model will be useful to find out if game-based learning can increase student interest from situational to individual [63]. Particularly, two survey instruments that are developed by using Hidi's model, will be used in this study. The details about these surveys can be found in the methods section of this document.

In conclusion, stimulating interest in students, especially in fields like engineering, requires an integrative approach that combines engaging instructional methods, student autonomy, and clear relevance to professional aspirations. By nurturing interest through these phases, educators can significantly enhance student motivation, leading to higher academic achievement and persistence in their field of study.

Recent developments in education emphasize the importance of engaging learning techniques to increase student motivation [63], [66]. In game-based learning (GBL), the interactive and challenging nature of games can stimulate students' interest (games should not be not too challenging, as argued by [67], especially when learning sustainability concepts and making decisions about them. GBL engages students by offering immediate feedback and iterative challenges, which promote engagement. This can help educators and game designers create more engaging, interest-driven educational tools, particularly in the subject area of sustainability.

This study considers interest an important factor, and utilizes interest surveys to determine increase in student interest pertaining to a sustainability-relevant course module. Further information about the interest surveys is provided in the 'instrumentation and measures' subsection.

Methods

This study's design is quasi-experimental, which is quantitative in nature and is based on post-positivist philosophical assumptions [68]. This study examines the relationship between the following factors: a) sustainability knowledge transfer, b) problem solving skills, and c) role of sustainability game in fostering student interest in sustainability-related course content. This is central to answering the research questions through quasi- experimental design [68].

We aim to introduce a computer game in the Environmental Life Cycle Assessment course, which is offered as an elective for the Green Engineering minor in the undergraduate engineering program at a large southeast university in the US.

Research Questions

The two research questions guiding this study are:

1. Do students who are provided with game-based supplementary material (SusLyfe) perform better in class assessment for a sustainability-related module than students who do not receive a supplementary game?

   We hypothesize that students who play SusLyfe will have higher performances in class assessments as compared to students who are being provided a traditional learning modality (class lectures).

2. Is implementing a game-based approach in the Circular Economy Analytics course effective in fostering student interest?

   We hypothesize that the majority of the students will find the game interesting to play and learn, which in turn will increase their motivation to engage with the course content.

Study Design

This study focuses on the role of game-based learning in sustainability education through a quasi- experimental design, which is quantitative in nature and is based on post-positivist philosophical assumptions [68]. By comparing a control group that receives traditional teaching approaches only with an intervention group that receives traditional instruction alongside a computer game designed for sustainability education, the study is set to evaluate student performance improvements in course assessments. An additional point of inquiry is whether playing the game leads to an increased interest of students in sustainability which may manifest in an increased engagement with the course content.

In terms of timeline, the study will be conducted in two phases: Phase I will comprise the pilot version of the game, and may be introduced in Fall 2026 or Spring 2027. Following that, data collection from Phase I will be used to iteratively modify the game to improve it for more optimal knowledge transfer and stimulation of interest in sustainability. Consequently, Phase II of the study will be conducted in the semester following Phase I and will include the iterated version of the game.

Sample

Following the criteria defined by Creswell [68], purposive sampling is used in this study, which means that the participants and site is selected intentionally by the researcher. The sampling criteria are determined as students in their junior year of study because of two reasons: firstly, the junior year in undergraduate programs is a time when the students get a chance to learn about sustainability. Secondly, capstone courses and junior-senior year projects in engineering let the students make informed design decisions in their projects, providing them flexibility to choose from a number of design processes and materials [69]. The study site is the Circular Economy Analytics course taught at a large southeast university in the US.

Sample Size

Sample size is calculated through power analysis using G*Power (version 3.1.9.7) [70]. The sample size computed for a medium effect size and with four predictor variables (mentioned in the instrumentation subsection) with an α of 0.05 (p-value) was 46. The decision was made to increase sample size for each group (control group and intervention group) to 50 to account for attrition and to minimize mortality threat to internal validity [68].

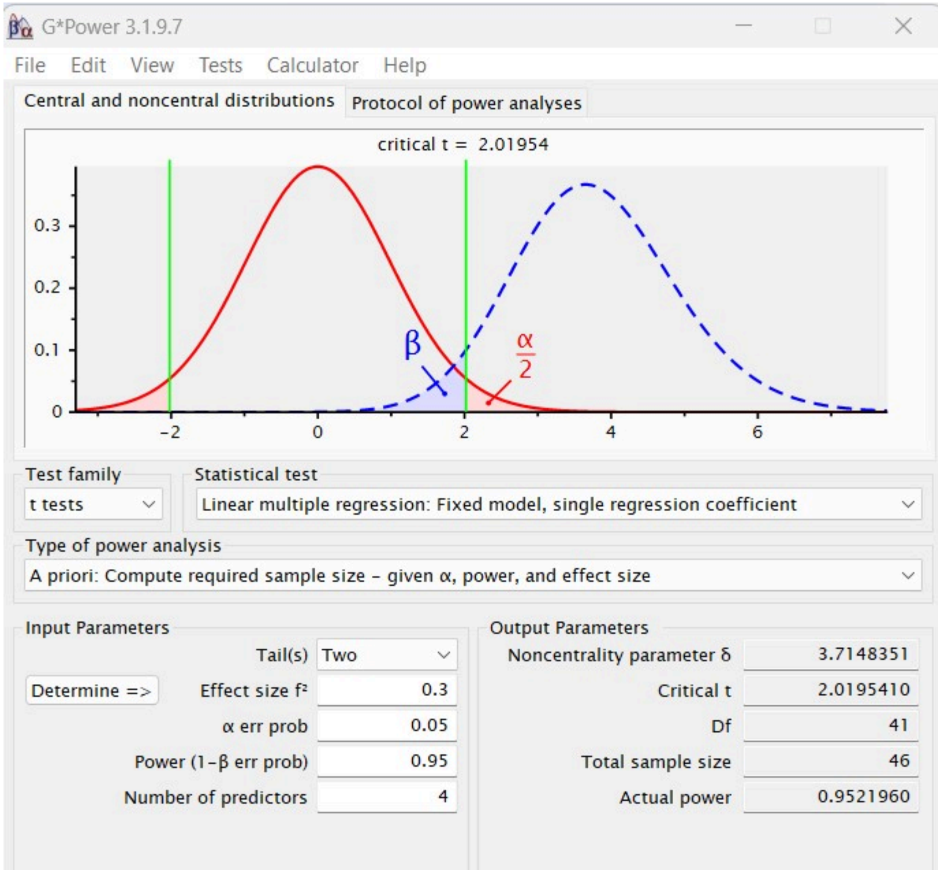

*Figure 3: Sample Size Calculation Using G*Power*

Study Settings. The pilot version of the computer game will be introduced in one of the two sections in a Circular Economy Analytics course offered as an elective course as part of the undergraduate engineering minors at a large southeast university in the US. The course is subdivided into six modules, with one module named "Transitioning from Linear to Circular Functions". This module accounts for 20% of the total time allocated towards the course. Students enrolled in the section that will receive the game as an intervention (intervention group) will be required to play the game as a take-home assignment in addition to the lectures they receive in the module.

As is the standard process for experimental studies in engineering education [71], the students in the control group will be engaging in learning sustainability concepts via attending lectures only. As mentioned earlier, the same instructor will teach both sections. To provide equal learning opportunities to all students, if the study findings suggest that a game-based approach is more beneficial to students' learning outcomes, at the end of the study, students in the control group will be given access to the game.

Instrumentation and Measures

Outcome Variables

Performance on Class Assessments. The course will consist of assessments through the semester in accordance with learning modules. Students' performances on the assessments related to the transition module will be considered as a score for every student. This will be a direct measure of their learning from the course itself (control group) or the course and the intervention (intervention group). As such, I hope to include this assessment in overall measure for this study to ensure objectivity and minimize researcher bias [68].

Individual Interest Questionnaire (IIQ). The purpose of this survey is to establish if students have already developed an individual interest in sustainability before the start of the study. This survey was developed by Rotgans [72] as part of their study on finding student interest levels in high-school students studying biochemistry. They developed this survey to collect data on individual student interest regarding a specific subject domain. The survey is inspired by the original work of Linnenbrink-Garcia et. al [73], and consists of 7 questions in total, all of which are related with individual interest. This makes it a suitable instrument to include in both pre- and post-test measures since it will provide baseline data about pre-existing student interest about sustainability in engineering. The measure has been validated and tested for reliability [72].

Situational Interest Survey. As a post-study measure, the purpose of this survey is to assess if students' interest in sustainability material have been promoted from situational to individual, and if they give more value to sustainability. This survey is proposed by Høgheim & Reber [74] as part of an effort to quantitatively assess knowledge and concepts of mathematics among students. The survey, also inspired in part by Linnenbrink-Garcia et. al [73], consists of 28 items that are all based on 5-point Likert scale, encompassing questions about individual interest in subject area, perceived competence, triggered and maintained situational interest, perceived value, and task effort. Scale reliabilities for this survey have been reported [74]. For my study, this survey is an effective instrument to measure changes in interest levels of students over the course of the 'Transitioning from Linear to Circular Functions' module.

Covariates/ Control Variables

Demographics. Differences in performance of students on the basis of 'age' and 'gender' as demographic covariates will be controlled for in this study.

Previous Gaming Experience. Students who have previously been involved in gaming for a significant amount of time might get an edge over the students who have not, in terms of performance on the game. For that purpose, we need to control for 'previous gaming experience' in the data analysis.

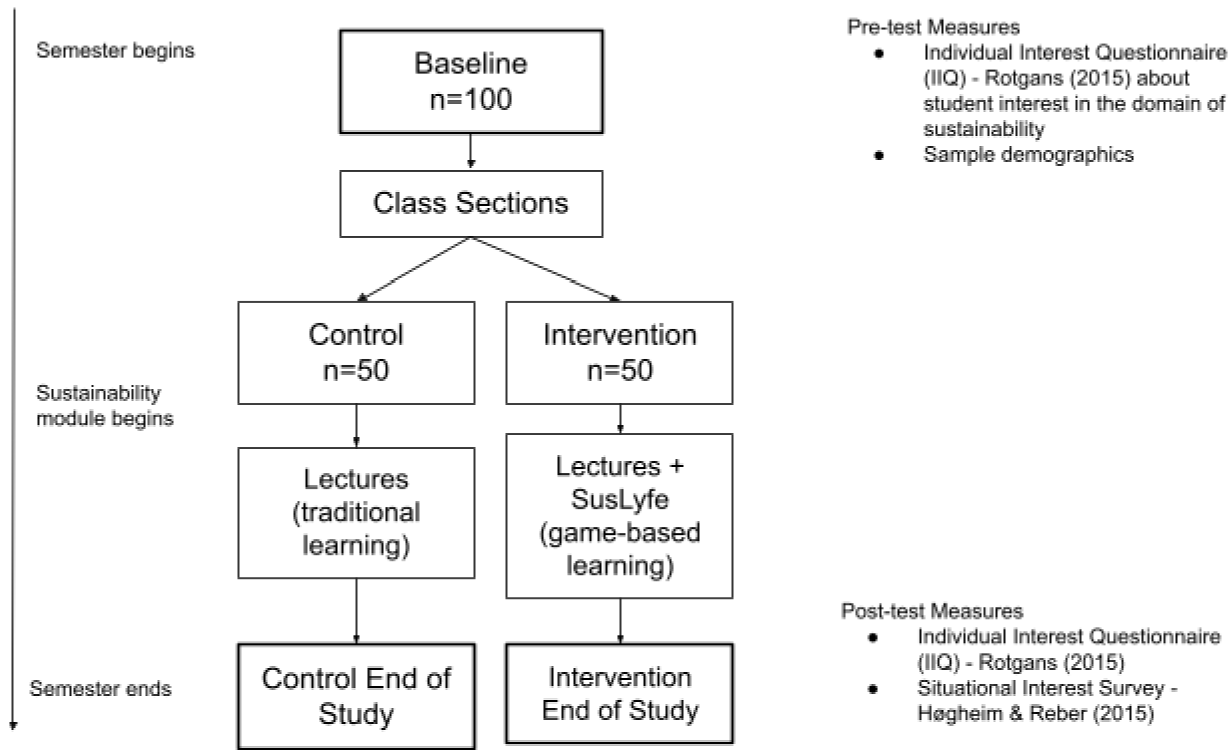

Figure 4: Overview of Study Design

SusLyfe. This study aims to measure the impact of playing a sustainability game, in this case the SusLyfe, on undergraduate engineering students. SusLyfe is intended to be an educational game, designed for personal computers (PC) as engineering students need PCs as a requirement for many courses. The design criteria of this game are informed by Fotiadis and Sigala [75] who suggest that in order for a game to deliver the learning objectives, it should consider aspects such as pedagogical principles, design elements, information provision, and students' evaluation system. In a rather practical sense, these aspects are realized by Annetta's framework for serious game design [76], which is followed by this study. Annetta's framework suggests that six elements are important in serious game development: which are briefly explained as: a) conveying character identity to let other players know of their presence and activity, b) player engagement and immersion in gameplay to make sure that players are attentive and motivated, c) interactivity of game, d) increasing complexity of game with player progress, e) informed teaching to capture data about players' decisions and game results, and finally, f) instructional or scaffolding systems to guide players throughout the game.

SusLyfe design. To capture the elements described above, we make design considerations for the version of SusLyfe game that is used for purposes of this study. For instance, the game's environment is based on decision making scenarios where the players can choose between three characters who all have access to many different elements that they can use to build mechanical machinery and products (element: identity). But the catch is that the elements are available in limited quantities. Certain elements are sustainable and others are not (in terms of recyclability and biodegradability). Easily accessible elements are not sustainable. Now, if the user gets easily accessible elements, they can build their projects faster. However, it will cost them in the long run because the game is programmed to destroy the unsustainable elements after a certain amount of time (elements: increasing complexity, immersion). The player has to keep account of which elements they have used to make calculated design decisions about their projects, so they can rebuild or replace certain machinery components in time before they get destroyed. On the brighter side, there is an option to sell the projects to certain other players and exchange certain elements as well (elements: interactivity, complexity). Players can generate profit and/or get bankrupt based on their short-term and long-term design decisions (element: informed teaching).

In this way, players will learn about sustainability of the planet. While playing the game, displaying messages about why humans should care about the planet's sustainability is very important and contributes toward the final element of educational game design, called "instructional".

Current State of the Game. SusLyfe is still undergoing development, and will be ready to be piloted before the start of Spring 2025. An overview of the gameplay will be demonstrated to the committee members as a 'vertical slice' [77] that will span for 2-3 minutes during the proposal presentation. As such, the currently developed level of the game boasts a single-player educational learning environment wherein the main character is an engineer who wakes up to find himself stuck on a remote island with his broken rocketship.

The main objective of the game is to explore the environment and search for objects that can be utilized to build the broken parts of the rocketship, so that the engineer can fly up to reach the International Space Station. The objects comprise randomly scattered plastic buckets, metal machinery, and wooden structures to mention some. Several properties for these objects are displayed as a pop-up on the screen when the character is in the vicinity of the object, which include color-coded information about materials used in their making, mining/production locations around the world, impact on environment, biodegradability, and recyclability.

Both sustainable and unsustainable objects can be used to build the rocketship, although the level of difficulty for finding objects made of sustainable materials is higher than those made with unsustainable materials. . However, the consequence of using unsustainable materials is that the rocketship will be able to cover less distance if built with unsustainable materials. In this way, players' decision making will impact the outcome of the game.

This vertical slice of the game will exhibit a scenario of linear economy, with no circularity indicators. However, the pilot version of the game will include a circular economy system where the players' choices about materials used to build the rocketship will also impact the environment and biodiversity around them on the island. For example, use of too much plastic material will result in production of non-biodegradable waste and consequently a huge carbon footprint which will result in dead animals in the forest and dead fish in the lake on the island. On the other hand, making sustainable design decisions will result in an efficient rocketship propulsion as well as preservation of biodiversity and an overall cleaner landscape in the game. As mentioned earlier, the pilot version of the game is scheduled to be completed before the start of Spring 2027 semester.

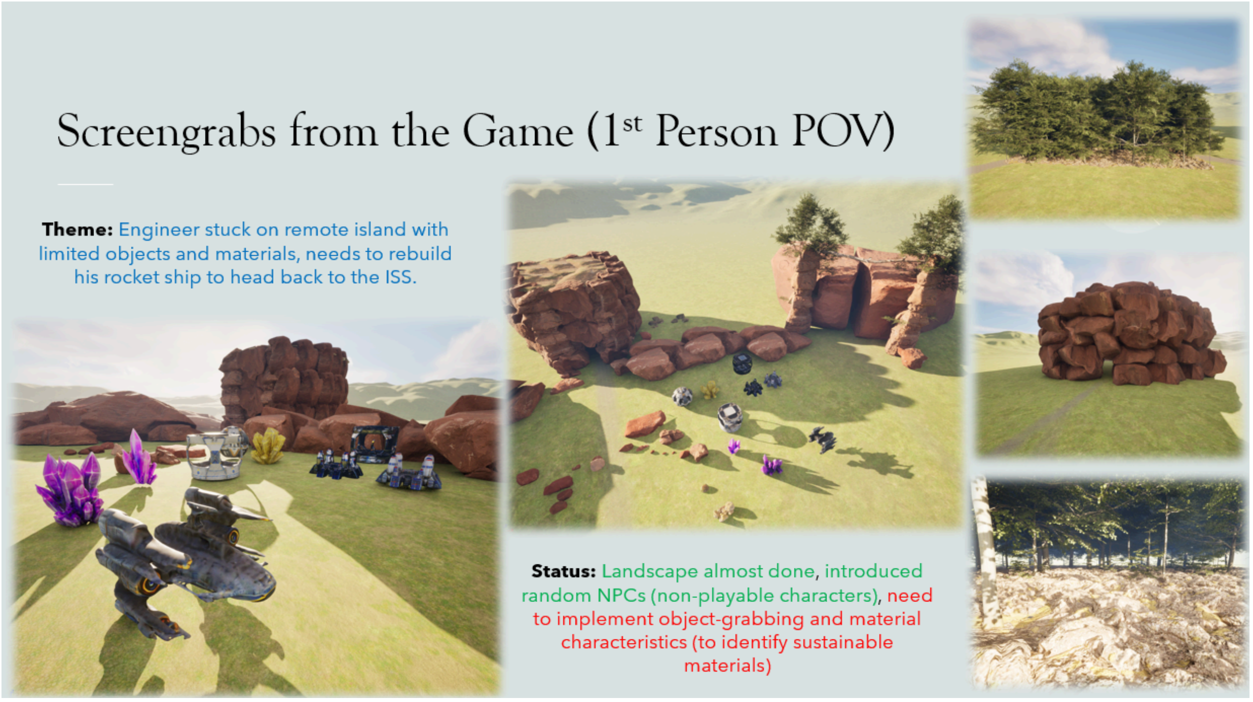

Figure 5: Screengrabs from the development phase of the SusLyfe video game

Recruitment

Recruitment of students is to be done from a sustainability course, which is an elective course aiming to provide students with knowledge of analytics of circular economy. Traditionally, the course is lecture-based and the course instructor teaches about conceptual knowledge of sustainability in class, specifically pertaining to circular economy analytics. For the purposes of this study, the participants will be divided into 2 groups, control group and intervention group [68]. During the course of the semester, the control group will be a section of students attending the traditional lecture-based instruction for this course, engaging in course assessments of their knowledge related to sustainability.

The intervention group will also attend the lecture-based classes, but they will additionally have access to the SusLyfe game, and will be asked to play the game for as a take home assignment class lectures related to the course module named 'transitioning from linear to circular functions'. In total, we will have a control group sample of n = 50 and an intervention group sample of n = 50.

Data Collection

The data collection will be done both before the semester starts and after the transition module ends. Demographic data, as well as prior interest in sustainability will be collected for all the participants before the semester begins to establish a baseline measure. The data from the two interest surveys will be used as a pre-post test measure (measured at the beginning of the semester and after the end of the transition module). The data from the in-class assessments about sustainability will be collected at the end of the transition module and will be considered as a measure of student learning outcomes.

Additionally, after every lecture, attendance will be recorded for students in the control group and the experimental group who play the SusLyfe game, and a participation "course engagement" grade will be assigned to them. The course engagement grade will help keep track of whether both groups are participating in the coursework and are compliant with the study's intended learning approaches they are provided with.

Data Analysis Plan

Comparisons of demographics and baseline measures will be conducted through t-tests and chi-square tests for the control and intervention groups to assess any pre-existing differences at baseline. Validity of the scales (surveys of interest) will be assessed through the Cronbach alpha. In addition, exploratory factor analysis (EFA) will be performed on the same scales mentioned above, to determine the reliability of the scales.

A linear regression model will be used to compare the outcome measures for control and intervention groups while controlling for sample demographics and pre-test performance where applicable. Demographics will include age and gender, since literature indicates variable performance and motivation levels of students in games based on their gender and age [78], [79], [80]. Pre-test performance will comprise baseline performance measures which are the surveys discussed in the instrumentation section.

Protocol for Implementation: IRB Approval

Approval from the Institutional Review Board (IRB) is an essential step for data collection to ensure the protection of sensitive information and other ethical concerns relevant to the study participants [81], such as consent, anonymity, and confidentiality, such that there is minimum risk of harm to the participants (AERA Code of Ethics, [82]). Since the study we are proposing will involve interactions with human subjects and collection of their demographics information and surveys, we plan to comply with the AERA Code of Ethics [82].

The IRB approval process at the large southeast university in the US is carried out through an online protocol submission system, and includes a number of steps such as uploading a detailed research protocol document, consent forms for human subjects, interview or survey questionnaires (if any), and recruitment emails/flyers. The IRB officials approve or reject the protocol based on the level of risk to the human subjects.

Limitations

As this quasi-experimental study is designed to measure student performances toward particular sustainability-related modules, the results of this study are currently limited to sustainability courses in undergraduate engineering contexts only. This limits the generalization of the study to broader contexts such as non-engineering disciplines. Moreover, the study is not relevant to students who are not interested in gaming. Also, the students' response bias while answering the self-reported interest questionnaires cannot be completely ignored. The design and development process of the SusLyfe game itself is also complex, and is limited by our (researchers') proficiency in Unreal Engine development at this time.

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Appendices

Appendix 1: Interest Survey
Note: This is a 5-point Likert scale inventory where options range from 1- “Totally Disagree” to 5- “Totally Agree”. Items with (R) are reverse-coded.

Individual Interest (Sustainability):
- I think sustainability is meaningless (R)
- Since sustainability is fun, I do not want to give it up
- For a while now, I have found sustainability to be boring (R)
- sustainability is important to me

Perceived Competence:
- Sustainability is hard for me (R)
- I am hopeless in sustainability (R)
- I have always performed well in sustainability
- I am good at sustainability
- I regard myself as competent in sustainability

Triggered Situational Interest:
- I liked the learning material
- The learning material caught my attention
- I found the learning material boring (R)
- The learning material was fun to work with
- I found the learning material engaging

Maintained Situational Interest:

- I found it to be boring (R)
- I liked what I learned here
- I thought it was interesting
- I found it intriguing
- I did not like what I learned here (R)

Perceived Value:

- What I learned here was useful for me
- I think this is valuable to learn
- What I learned here is completely useless (R)
- I could have done this again since it is valuable to me
- I see the value of what I learned here

Task Effort:

- I made an effort solving the tasks
- I tried as hard as I could when I worked with the problems
- I did not put much effort into solving the tasks (R)
- I worked as hard as I could on the tasks

Appendix 2: Individual Interest Questionnaire (IIQ)

1	I am very interested in sustainability	1	2	3	4	5
		Not true at all	*Not true for me*	*Neutral*	*True for me*	*Very true for me*
2	Outside of school I read a lot about sustainability	1	2	3	4	5
		Not true at all	*Not true for me*	*Neutral*	*True for me*	*Very true for me*
3	I always look forward to my sustainability lessons, because I enjoy them a lot	1	2	3	4	5
		Not true at all	*Not true for me*	*Neutral*	*True for me*	*Very true for me*
4	I am interested in sustainability since I was young	1	2	3	4	5
		Not true at all	*Not true for me*	*Neutral*	*True for me*	*Very true for me*
5	I watch a lot of sustainability-related TV programs (e.g., Discovery Channel)	1	2	3	4	5
		Not true at all	*Not true for me*	*Neutral*	*True for me*	*Very true for me*

6	Later in my life I want to pursue a career in sustainability or a sustainability-related discipline	1	2	3	4	5
		Not true at all	*Not true for me*	*Neutral*	*True for me*	*Very true for me*
7	When I am reading something about sustainability, or watch something about sustainability on TV, I am fully focused and forget everything around me	1	2	3	4	5
		Not true at all	*Not true for me*	*Neutral*	*True for me*	*Very true for me*

Appendix 3: Post-Study System Usability Questionnaire (PSSUQ)

PSSUQ Version 3 consists of 16 questions with 7 options (+ NA option) to choose from. The sample below shows a PSSUQ questionnaire to measure the usability:

1. Overall, I am satisfied with how easy it is to use this system.
2. It was simple to use this system.
3. I was able to complete the tasks and scenarios quickly using this system.
4. I felt comfortable using this system.
5. It was easy to learn to use this system.
6. I believe I could become productive quickly using this system.
7. The system gave error messages that clearly told me how to fix problems.
8. Whenever I made a mistake using the system, I could recover easily and quickly.
9. The information (such as online help, on-screen messages, and other documentation) provided with this system was clear.
10. It was easy to find the information I needed.
11. The information was effective in helping me complete the tasks and scenarios.
12. The organization of information on the system screens was clear.
13. The interface of this system was pleasant.
14. I liked using the interface of this system.
15. This system has all the functions and capabilities I expect it to have.
16. Overall, I am satisfied with this system.