Enhancing Sustainability Education: The Impact of Gamification and Storytelling on Engagement and Knowledge Acquisition

Alexander Rudolf (2531631)

Department of Behavioural, Management, and Social Sciences, University of Twente

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1st Supervisor: Dr. M. Farrohkhnia

2nd Supervisor: Dr. Ir. PW de Vries

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Abstract

Educational research heavily focuses on innovative techniques, such as the use of game elements and storytelling in digital learning environments. These tools aim to enhance users' engagement and learning outcomes. However, their efficacy in the context of Education for Sustainable Development (ESD) is underexplored. This study investigates the impact of these elements on learners' engagement and knowledge acquisition. Specifically, the study aimed to test whether gamified environments, with and without the use of storytelling elements, would significantly increase engagement and learning compared to a control group. The study employed a between-subjects experimental design with three groups: a control group, a gamification group, and a gamification with additional storytelling group. Participants ($N = 42$) engaged in several activities related to sustainable development within a digital learning environment. Engagement was measured after these activities (self-reported), and knowledge acquisition was measured before and after the learning activity. The tasks in the interactive learning environments were self-designed, and based on the condition, game-, and storytelling elements were added. Contrast analysis, ANOVA, and ANCOVA were conducted to test the effects. The results revealed no statistically significant differences in engagement or knowledge acquisition across the groups. Even though the study's results are insignificant, they still provide valuable insights, such as highlighting the role of prior knowledge, which was a main contributor to knowledge acquisition. This highlights the importance of adaptable scaffolding in digital learning environments to account for different types of learners.

Introduction

Climate change poses multiple challenges to society, such as severe weather events, rising sea levels, and accompanying consequences like food like increased flooding, food scarcity, and species redistribution at a global scale (Pecl et al., 2017). These consequences are caused by human-mediated climate change and affect economic development, food security, human health, and national security (Pecl et al., 2017; Campbell et al., 2007). To counteract this development, strategies to decrease the speed of climate change are essential. One of these strategies is a global shift towards more sustainable behavior among individuals (Stern, 2000). To achieve this shift in behavior, education is a critical change component. To support education in this domain globally, UNESCO launched an initiative called the Decade of Education of Sustainable Development (DESD) (UNESCO, 2005; UNESCO, 2020). This program has successfully advanced global sustainability education in formal and informal education (UNESCO, 2020). Research also shows that many countries' awareness of environmental and sustainable development issues has significantly increased (Pauw et al., 2015; UNESCO, 2020).

Through a holistic approach, the education for sustainable development (ESD) also focuses on developing education and research, where higher educational institutions play a pivotal role (Findler & Schönherr, 2019). Research also shows that students of higher education who receive ESD tend to engage in more sustainable behavior, like recycling and choosing greener energy sources (Boca & Saracli, 2019). It is also highlighted that ESD helps to close the gap between rich ecological awareness and specific environmentally beneficial behavior by encouraging active participation in environmental activities, fostering a culture of environmental responsibility, and promoting volunteerism (Boca & Saracli, 2019).

Even though these findings highlight the critical role of education in advancing sustainable development, the high reliance on traditional educational practices has led to less efficient teaching in this domain (Lozano et al., 2019; Evans, 2019). For instance, Lozano et al. (2019) argue that conventional lecture-based approaches often fail to effectively develop the necessary competencies for addressing sustainability challenges. Similarly, Evans (2019) critiques the predominance of didactic methods because they are inadequate for fostering critical thinking and experiential learning required for meaningful engagement with sustainability topics. Moreover, UNESCO's (2018) report highlights that current ESD practices must move from traditional methods to more transformative and problem-based learning approaches to achieve the intended outcome. Research and development around the domain of education in the past decades revealed substantial flaws in traditional learning and teaching methods (Baş & Kivilcim, 2021; Kyriakides et al., 2013; Ryan & Deci, 2000; Pauw et al., 2015). It is mentioned that traditional educational methods often rely mainly on passive learning with a teacher-centered approach focusing on memorization of content, which can lead to disengagement and lack of motivation among students (Baş & Kivilcim, 2021; Ryan & Deci, 2000). Hence, to ensure effective learning and maintain student engagement, it is essential to research innovative, student-centered learning methods and their functionalities (Baş & Kivilcim, 2021).

Transitioning from these traditional methods, one promising approach is game-based learning (GBL), which utilizes digital or non-digital games to enhance learning outcomes by fostering learner engagement (Plass et al., 2015). UNESCO (2020) underscores the importance of supporting innovative teaching methods like digital learning tools and interactive approaches. The organization advocates for teaching approaches that promote engagement, develop problem-solving skills, and facilitate understanding of more profound concepts within the sustainability domain (UNESCO, 2020). The GBL teaching approach aligns well with such criteria.

Theoretical framework

Game-Based Learning

Potential benefits of GBL can be found in previous research. Studies have already found positive effects of GBL for ESD in higher educational settings (Emblen-Perry, 2018; Lozano et al., 2019; Plass et al., 2015; Sánchez-López et al., 2022). The findings of these studies suggest that GBL leads to enhanced engagement and motivation, improved understanding of sustainability concepts, and a development of critical thinking and problem-solving skills. In a study that tested a sustainable strategies game in the context of higher education, students reported high levels of engagement, and results also showed an increase in understanding of complex sustainability issues (Emblen-Perry, 2018). Moreover, other findings suggest that implementing GBL can effectively develop key sustainability competencies, such as critical thinking and problem-solving (Lozano et al., 2019). In addition, it was found that GBL fosters interdisciplinary learning, which is also an integral part of understanding topics related to sustainability (Lozano et al., 2019).

Despite the potential of GBL in increasing students' engagement with learning materials and enhancing their cognitive and problem-solving skills, this teaching approach also faces several challenges that impede its broad application. Specifically, developing serious games, integral to GBL, is both time- and resource-intensive (Lozano et al., 2019; Szilas, 2022). This limitation reduces the availability of games for more specific topics. Additionally, the lack of technical expertise among educators, the high cost of game maintenance and updates, and the difficulty in aligning game content with educational standards pose significant barriers to the widespread adoption of GBL (Sailer et al., 2017; Szilas, 2022)

Gamification

To address these challenges while retaining the benefits of GBL, the technique known as "gamification" can be employed. Gamification involves using game-related elements in non-game learning environments, offering a more straightforward and less resource-intensive approach (Sailer et al., 2017). This technique has become increasingly popular in the educational landscape over the past decade (Dehghanzadeh et al., 2024; Hamari et al., 2014; Khaldi et al., 2023). Notable examples of online learning environments utilizing gamification include mobile applications like Duolingo, Kahoot!, or Mimo. These applications employ gamification techniques to enhance the user experience and increase engagement levels. Dehghanzadeh et al. (2024) found that gamification strategies in higher education lead to heightened student engagement levels. By incorporating game elements such as leaderboards, points, and rewards, students become more motivated to participate actively in the learning process. A meta-analysis of the effects of gamification highlights that these elements create a sense of competition and achievement, which drives student participation (Hamari et al., 2014; Dehghanzadeh et al., 2024). It is also emphasized that gamification can increase intrinsic motivation, particularly when game elements align with students' interests and learning content (Khaldi et al., 2023).

Research suggests that the primary mechanism underlying the benefits of gamification is the enhancement of intrinsic motivation (Sailer et al., 2017; Chans & Castro, 2021). This increased intrinsic motivation is typically linked to several positive educational outcomes, including a deeper engagement with learning materials (Khaldi et al., 2023), improved retention of information (Khaldi et al., 2023; Rahmani-Katigari et al., 2023), and elevated levels of satisfaction (Chans & Castro, 2021). To further explore the impact of gamification on intrinsic motivation, self-determination theory (SDT) provides a valuable framework (Sailer et al., 2017; Chans & Castro, 2021). Initially proposed by Deci and Ryan (1985), SDT has been extensively applied in the context of games to understand motivational dynamics (Sailer et al., 2017; Przybylski et al., 2009). SDT posits that there are three basic psychological needs that drive intrinsic motivation:

- **Competence**: This need reflects the desire to feel adequate and successful in undertaking challenges and achieving goals.
- **Autonomy**: This involves the desire for agency and control over one's actions, encompassing decision freedom—the ability to choose from multiple options—and task meaningfulness—the alignment of tasks with personal goals and values (Sailer et al., 2017).
- **Social Relatedness**: This need highlights the importance of feeling connected to others, forming meaningful relationships, and feeling valued within a community.

When these needs are satisfied, intrinsic motivation is significantly enhanced. This mechanism implies that if game elements aim to increase intrinsic motivation, they should be carefully chosen to address these specific psychological needs effectively. Before delving into the specific game elements that cater to these needs, it is essential to conceptualize the various types of game elements available.

Taxonomy of Game Elements

Building on the foundation laid by earlier discussions, growing research aims to conceptualize and categorize different classes of game elements (Khaldi et al., 2024; Sailer et al., 2017; Toda et al., 2019). Most studies emphasize the significance of three specific game elements—points, badges, and leaderboards (PBL), citing them as the most prevalent and effective (Khaldi et al., 2024; Sailer et al., 2017). However, a detailed categorization is necessary to foster a greater understanding of the diverse game elements and provide guidelines for their implementation. Through extensive collaboration with other experts, Toda et al. (2019)

developed a comprehensive taxonomy of game elements (Figure 1), asserting that these elements can be classified into five distinct dimensions based on their underlying mechanisms:

1. **Performance**: This dimension focuses on delivering feedback to learners about their progress and performance within a digital learning environment. It includes elements such as points, badges, levels, and progression.

2. **Ecological**: Directly related to the environment where the game elements are implemented, this dimension features elements like chance, rarity, economy, and time pressure, all of which aim to enhance user interest and engagement.

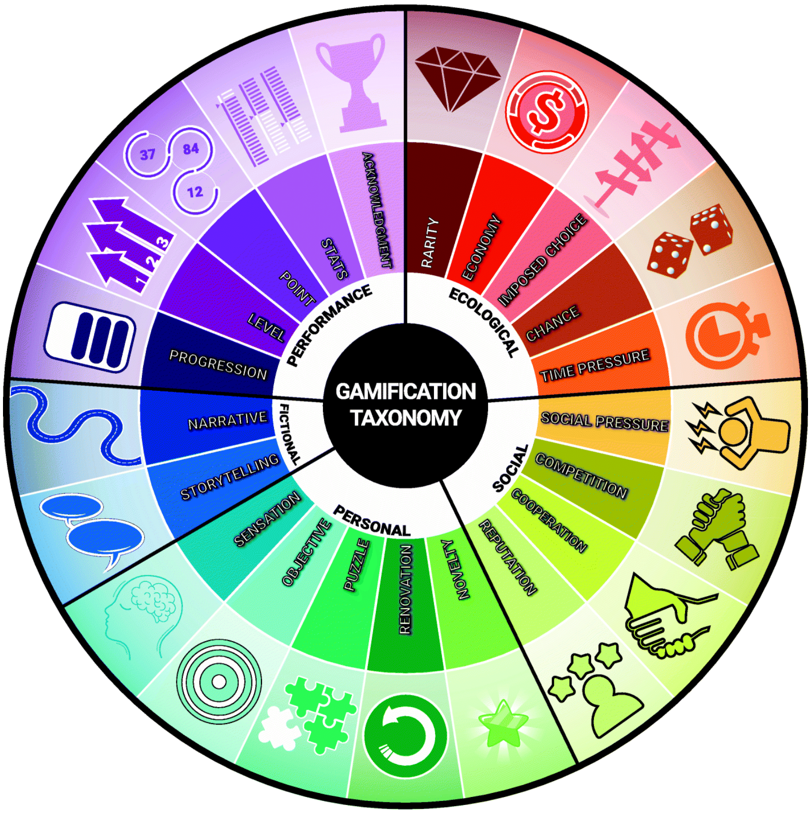
3. **Social**: The social dimension pertains to interactions between multiple learners within the environment, enhancing the social dynamics where users can collaborate and compare achievements. Typical elements include competition (leaderboards, scoreboards, etc.), cooperation, and social pressure.

4. **Personal**: Focused on the individual user within the environment, this dimension includes elements such as sensation, objective, and novelty, designed to provide personal meaning and motivation for the learner.

5. **Fictional**: A mixed dimension that relates to the user and the environment, encompassing narrative and storytelling elements that aim to enhance task meaningfulness by providing a storyline.

Figure 1

Taxonomy of Gamification Elements



This framework not only deepens the understanding of how different elements interrelate but also facilitates a structured approach to studying and implementing game elements in educational settings. However, to fully appreciate their effectiveness, examining the psychological mechanisms these elements trigger is crucial. Understanding these mechanisms sheds light on why specific game elements are essential in designing engaging learning materials.

Toda et al. (2019) describe how various game elements, such as points, levels, and leaderboards, trigger psychological processes that increase user engagement. Points are one of the most fundamental elements, frequently used in various applications to provide direct extrinsic feedback on user performance. They quantify progress and make it measurable, with scores, experience points, or skill points reinforcing behavior and motivating further action.

Progression elements, like progression bars, visually track the user's advancement, enhancing their sense of achievement and encouraging continued participation. Levels add a hierarchical structure, rewarding users with new advantages and incentives as they advance through the system.

Leaderboards introduce a competitive, dynamic element, motivating users to improve their performance and compare their standing with others, which taps into social comparison and competition (Krath et al., 2021). Time pressure adds a sense of urgency, encouraging users to act quickly to gain rewards and leveraging the psychological principle of scarcity (Cialdini, 2009; Yildirim, 2016). Similarly, rarity engages users by introducing the anticipation of unknown rewards, playing on the psychological appeal of unpredictability (Skinner, 1965; Toda et al., 2019). These elements often interact synergistically. For instance, points can accumulate to unlock achievements, increase levels, and advance users on progress bars. This interconnected design makes performance more visible and comprehensible, ultimately fostering user engagement.

Additionally, psychological need satisfaction, as explained in the SDT (Deci & Ryan, 1985), has been linked to specific game design elements (Table 1) (Sailer et al., 2017). When comparing this connection with the gamification taxonomy proposed by Toda et al. (2019), it becomes clear that the need for competence is tied to the most common and frequently used game elements (Hamari et al., 2014). In contrast, elements related to the need for autonomy and social relatedness are less frequently applied (Toda et al., 2019). However, research shows that competence, autonomy, and relatedness are all crucial for increasing engagement and encouraging future game-playing behavior (Ryan et al., 2006; Sailer et al., 2017). This highlights the importance of implementing game elements that fulfill all three psychological needs. However, there is a lack of robust evidence on the effectiveness of implementing specific game elements (Seaborn & Fels, 2015), pointing to the need for further empirical exploration. (Seaborn & Fels, 2015).

Table 1

Psychological Needs and Their Connected Game Elements

Psychological need	Game element
Need for competence	Points
	Performance graphs
	Badges
	Leaderboards
Need for autonomy (decision freedom)	Avatars
Need for autonomy (task meaningfulness)	Meaningful stories
Need for social relatedness	Teammates
	Meaningful stories

One element mentioned in Table 1 but with limited acknowledgment in research is the game element of storytelling. Storytelling involves incorporating audio cues, text-based narratives, and other elements to add greater meaning to the learning environment (Palomino et al., 2019; Toda et al., 2019). Everything related to the story contributes directly to the user's narrative experience within the environment (Palomino, 2015). Although storytelling is considered an important component and essential part of a gamified learning environment, only one framework addresses this concept in a meta-analysis on gamification (Mora et al., 2017), indicating a lack of research and awareness of its effectiveness. Palomino et al. (2019) emphasize the significance of storytelling because it adds purpose and meaning to actions within a gamified system. Furthermore, a well-crafted narrative enhances user experience, engagement, and motivation (Palomino et al., 2019; Toda et al., 2019).

Building on the theoretical foundations of gamification and its psychological mechanisms, it becomes clear that incorporating various game elements, including storytelling, can significantly enhance engagement and knowledge acquisition in educational environments. While the research has highlighted the importance of elements such as points, levels, and leaderboards, storytelling remains underexplored despite its demonstrated ability to add purpose and meaning to user actions. This gap in the literature, particularly in the context of ESD, warrants empirical investigation.

Despite the recognized potential of gamification in educational settings, research specifically addressing its application in ESD remains limited (Lozano et al., 2019; Sánchez-López et al., 2022). Furthermore, although a few studies have utilized game elements to enhance learning within the context of ESD (e.g. Emblen-Perry, 2018; Lozano et al., 2019; Plass et al., 2015; Sánchez-López et al., 2022), they often lack a robust theoretical underpinning, which is crucial for understanding and maximizing the impact of these elements in the context of education. Additionally, such studies have paid little attention to incorporating diverse game elements like storytelling, which, according to Mora et al. (2017) and further emphasized by Palomino et al. (2019), can add purpose and meaning to actions within a gamified system.

The Current Study

This study explores the impact of gamification and storytelling elements on user engagement and knowledge acquisition within an ESD learning environment. Therefore, an experiment was set up where users were introduced to an online learning environment with the topic of sustainability. The participants were separated into three conditions: control condition, gamification condition, and gamification with storytelling elements condition. Engagement and knowledge acquisition were measured in all conditions. Specifically, it is hypothesized that:

Hypothesis 1. Implementing game elements in an ESD learning environment will lead to a significant increase in user engagement compared to a learning environment without game elements.

Hypothesis 2. Adding storytelling elements to an ESD learning environment will significantly increase user engagement compared to an environment with game elements only.

Hypothesis 3. Implementing game elements in an ESD learning environment will result in a significant improvement in knowledge acquisition compared to a control condition without game elements.

Hypothesis 4. Adding storytelling elements to an ESD learning environment will result in a significant further improvement in knowledge acquisition compared to an environment with game elements only.

Methods

Participants and Design

A convenience sample was used, with participants recruited from the University of Twente Sona system, advertisements via WhatsApp, and advertisements on survey exchange platforms. Inclusion criteria required participants to be at least 18 years old and have a sufficient understanding of the English language. Initially, 100 users started the survey, but after filtering out unfinished and insufficient responses, 42 valid responses remained. The sample size was determined based on the available resources and the need to ensure a manageable data collection and analysis process. Table 2 shows the demographic data of the participants.

Table 2

Demographic Characteristics of the Participants

Characteristics	Category	*n*	%	*M*	*SD*
Age				26	5.2
Gender	Female	23	54.8%	26.79	5.1
	Male	19	45.2%	25.65	5.4
Education level	High School Diploma	13	31.0%		
	Bachelor's Degree	22	52.4%		
	Master's Degree	7	16.7%		
Nationality	German	32	76.2%		
	Dutch	2	4.8%		
	Other	8	19.0%		

Considerable attention was given to ethical considerations for people participating in this study. Informed consent was obtained at the beginning of the participation, and the participants were free to withdraw from the study at any time without consequences. The data was stored and treated confidentially on the platform Qualtrics. Moreover, approval from the ethics committee of the University of Twente was obtained, ensuring the rights and well-being of the participants were respected throughout the study.

The study employed a robust two-factor between-participants design with Gamification (present vs. absent) and Narration (present vs. absent) as independent variables and engagement levels and knowledge acquisition as dependent variables. The independent variables were carefully manipulated by incorporating game elements such as points and leaderboards, and storytelling elements into the learning environment, ensuring a comprehensive and rigorous study design. The primary outcome measures were engagement with the digital learning environment and students' knowledge about sustainability topics before and after the study session.

Materials

User Engagement Scale Short Form (UES-SF)

The User Engagement Scale Short Form (UES-SF) (Appendix 1) was used to measure participants' engagement with the digital learning environment. The UES-SF (O'Brien & Cairns, 2018) is a validated instrument (ω = 0.90) that assesses four dimensions of user engagement: focused attention, perceived usability, aesthetic appeal, and reward. Participants responded to 12 items on a 5-point Likert scale, ranging from 1 (strongly disagree) to 5 (strongly agree), with some items reverse-coded. Example items included statements such as 'I lost myself in this activity' and 'I felt rewarded by this experience'.

Self-Created Questionnaire on Sustainability Knowledge

A custom-designed questionnaire (α = .86) was developed to assess participants' knowledge of sustainability topics, specifically focusing on areas related to the study, such as food consumption, recycling, transportation, and water conservation (Appendix 2). The questionnaire consisted of 12 multiple-choice questions that covered key concepts presented in the learning environment. It was administered twice: once before and once after the learning experience. This design was specifically chosen to assess participants' prior knowledge of the topics covered in the learning environment and to evaluate the knowledge acquired afterward.

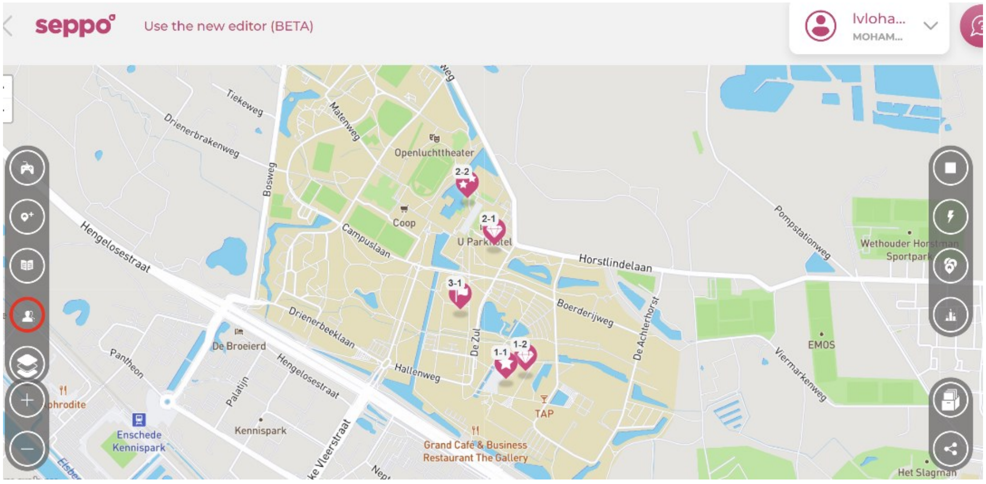
Digital Learning Environment

Activities.

Content and features from multiple existing sustainability-focused learning environments were evaluated to design the learning environment. The learning activity was designed and implemented using an online tool called Seppo (seppo.io). With this tool, a map-based learning environment featuring multiple exercises was created. The map of the University of Twente was used to connect the learning activities with corresponding locations on the university campus (Figure 2). Participants were asked to finish all levels on the map. Each level contained exercise types such as multiple choice, checkboxes, and match-pair activities. The environment featured activities on sustainable food consumption, recycling, water conservation, and sustainable transportation. Participants were asked to finish all tasks within the learning environment. Each category of tasks included at least one allocation activity (e.g., matching specific foods with their associated carbon footprint), a link to the University of Twente website providing detailed information on the topic along with additional content-related questions, and in two out of the three categories, a reflective open-ended question where participants were asked to consider their own behavior related to the topic.

Figure 2

Map of the University of Twente used as a Game Board in the Learning Environment.



Note: This figure shows the map displayed in the Gamification and the Gamification with Storytelling condition. The Control condition does not contain the levels and the bonus tasks.

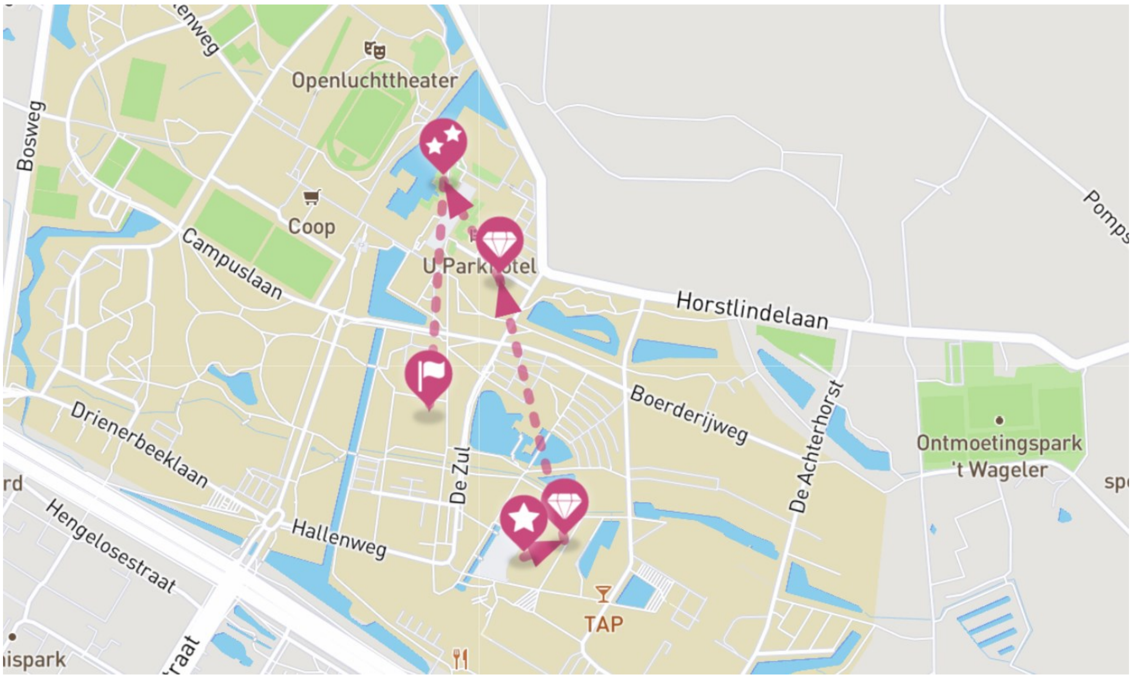
The conditions.

As previously mentioned, participants were divided into three conditions:

Control condition: In this condition, the content was presented without adding game elements. The exercises were presented in a set order without the use of levels. In Figure 3, you can see the map, including all levels shown from the beginning and connected by a path. The participants still received similar learning content without game elements such as points, leaderboards, or time pressure.

Figure 3

Map in the Control Condition

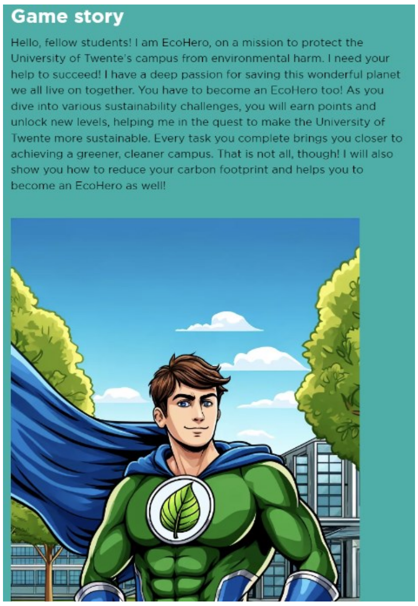


Gamification condition: To enhance learner engagement, several gamification elements were incorporated for this group, including points, a leaderboard, levels, progression, time pressure, and rarity. Points were awarded for each correct answer. The leaderboard was initially turned off in the control condition and was later displayed to show the participants' scores relative to others for comparison purposes (Appendix 3). Levels were implemented by organizing the exercises into three distinct levels (1, 2, and 3) (see Figure 2). Upon completing an exercise, participants received an on-screen message indicating, “new level unlocked”, allowing them to proceed to the next level. Progression was indicated by both the level system and a level progression status (Appendix 4). Time pressure was introduced by setting a visible time limit for completing each task (Appendix 5). Rarity was implemented by including “Bonus Tasks,” which were locked with a password and a provided hint (Appendix 6). The password for these tasks was provided in the previous task, and participants could request hints if necessary.

Gamification with narration condition: This condition included the same game elements as the Gamification condition, with the addition of a narrative. The narrative introduced the story of becoming an "EcoHero" tasked with saving the campus (Figure 3). This storyline was referenced throughout the exercises, with participants receiving new missions or feedback on their progress, reinforcing that they were on their way to becoming an EcoHero (Appendix 7).

Figure 4

Introduction of the Mission and EcoHero



Key differences between the conditions were that the control condition did not include elements such as points, leaderboard, rarity, and time pressure. Moreover, the gamification with storytelling condition included multiple storytelling elements in every task that referred back to the mission of becoming an EcoHero (Appendix 7).

Procedure

After receiving the study link via an online platform or directly from the researcher, participants were directed to a Qualtrics survey. First, they completed the pre-intervention section, which included informed consent and a pre-assessment of their sustainability knowledge. Following this, participants were introduced to the learning environment through an instructional text. Each participant was randomly assigned one of three PIN codes to access the learning environment. They were then prompted to click on the link to the Seppo platform (seppo.io) and enter the corresponding PIN code.

Upon entering the learning environment, participants engaged in a series of activities organized into three levels, each covering different sustainability topics. For the first two levels, bonus reflective tasks were included, where participants were asked in an open-text format to identify specific behavioral changes they could make regarding the relevant topics. The topics were linked to the University of Twente, and participants were required to visit the university's sustainability webpage to gather information. For example, the first task focused on sustainable food consumption. Participants were directed to the webpage "Sustainability on Campus: Food & Drinks", where they read about the university's goals for reducing CO_2 emissions by 2030. They then answered questions about these goals (e.g., Appendix 8).

The second level addressed water conservation and waste reduction, where participants identified personal strategies to reduce waste and water usage. The final task centered on sustainable transport, requiring participants to explore the university's proposed measures for sustainable transportation and assign CO_2 emissions to different transportation methods (e.g.,

Appendix 9). Participants in the gamification with narration condition received additional narrative instructions, referencing their mission to become EcoHeros.

After completing all tasks, participants returned to the Qualtrics survey, where they entered their chosen nickname during the learning activity to link their responses. They then completed the UES-SF questionnaire and the post-intervention sustainability knowledge assessment with randomized question order. Finally, participants were debriefed, and the study concluded.

Data Analysis

Before conducting inferential statistical analyses, relevant assumptions such as normal distribution, homogeneity of variances, and linearity were assessed, and the data was checked for significant outliers. No major violations were found, allowing us to proceed with the planned statistical tests to examine the hypotheses.

To analyze user engagement, a one-way analysis of variance (ANOVA) was performed to compare engagement scores across three conditions: control, gamification, and gamification with storytelling, identifying significant differences between group means. Custom contrasts were applied to provide a detailed comparison of the group means.

Descriptive statistics summarized pre-test and post-test scores across groups for knowledge acquisition, providing an overview of the data distribution. An analysis of covariance (ANCOVA) examined the effect of group membership on post-test scores, controlling for pre-test scores to account for initial differences. Finally, custom contrasts were applied to compare specific group differences in knowledge acquisition.

Results

Engagement

To test hypotheses 1 and 2, which predict an increase in engagement in the gamification and the gamification with storytelling elements group, a one-way ANOVA was conducted. The results indicated no significant differences in engagement scores between the groups, $F(2, 39) = 1.26$, $p = .295$. To further explore the differences between the groups, custom contrasts were performed using adjusted p-values to compare specific pairs of groups. As presented in Table 4, none of these contrasts showed a statistically significant difference. These results indicate no significant differences in engagement scores between the tested groups. Thus, we can conclude that Hypothesis 1 and Hypothesis 2 can be rejected because no significant differences in engagement scores among the groups could be found.

Table 3

Descriptive Statistics for Engagement Scores

Group	Mean	SD
Control	42.08	9.62
Gamification	44.07	9.05
Gamification + Storytelling	38.20	11.80

Table 4

Custom Contrasts for Engagement Scores

Contrast	Estimate	SE	t (39)	p
Control vs. Gamification	-1.98	3.98	-0.50	.621
Control vs. Gamification + Storytelling	3.88	3.98	0.98	.335
Gamification vs. Gamification + Storytelling	5.87	3.75	1.57	.126

Knowledge Acquisition

Descriptive statistics were calculated in order to summarize the pre-test and post-test knowledge scores across the groups (Table 5). There were slight differences in pre-test and post-test scores across the groups.

Table 5

Descriptive Statistics for Knowledge Acquisition

Group	Pre-Test	Post-Test	Change
Control	8.41 (3.42)	9.41 (2.87)	1.00 (1.65)
Gamification	8.26 (2.63)	9.73 (3.15)	1.47 (1.73)
Gamification + Storytelling	8.67 (1.80)	10.00 (1.64)	1.33 (2.09)
Total	8.45 (2.58)	9.74 (2.57)	1.29 (1.81)

An ANCOVA was performed to assess whether these differences between the groups are significant, as hypotheses 3 and 4 predict, controlling for pre-test scores to account for initial knowledge differences. The results of the ANCOVA revealed no significant main effect of Group on knowledge acquisition, F (2, 38) = 0.24, p = .787. However, it revealed that pre-test scores significantly predicted post-knowledge scores, F (1, 38) = 50.07, p < .001.

Moreover, custom contrasts were performed to compare knowledge acquisition across groups, adjusting for pre-test scores. The analysis revealed that none of the pairwise contrasts were statistically significant (Table 6), indicating that neither gamification nor gamification with storytelling significantly improved knowledge acquisition compared to the control group, contrary to the hypotheses.

Table 6

Custom Contrasts for Knowledge Acquisition (ANCOVA)

Contrast	**Estimate**	**SE**	**t (39)**	**p**
Control vs. Gamification	-0.467	0.715	-0.652	.518
Control vs. Gamification + Storytelling	-0.333	0.715	-0.466	.644
Gamification vs. Gamification + Storytelling	0.133	0.674	0.198	.844

Discussion

This study aimed to enhance the understanding of gamification functionalities within the context of ESD. Specifically, it aimed to investigate the effects of game elements and the isolated impact of storytelling elements in a gamified environment. This examination, particularly within the ESD context, represents a novel contribution to educational research. The specific impact of game elements in online learning environments with a standalone test of storytelling elements has not been researched in ESD.

Overall, in our study, no significant differences in engagement were observed between the control and gamification conditions, nor between the gamification conditions and the gamification with storytelling conditions. As a result, the first and second hypotheses were not supported. Similarly, no significant differences were found in knowledge acquisition in the post-test across conditions, leading to the rejection of the third and fourth hypotheses. However, the findings show that prior knowledge, measured with pre-test scores, predicts post-test outcomes significantly. Additionally, looking at the descriptive statistics, we can find increased engagement in the gamification condition compared to the other conditions and increased knowledge acquisition in both conditions with game elements compared to the control condition.

One of the most significant findings is the impact of prior knowledge on the learning outcomes. Although we could not support our hypotheses regarding increased engagement and knowledge gain, the analysis revealed that prior knowledge significantly predicted post-test performance. Regardless of the experimental condition, participants with higher prior knowledge showed a higher increase in knowledge acquisition. These findings are supported by constructivist learning theory (Vygotsky, 1978), which emphasizes that learners build new knowledge upon an existing cognitive structure. This suggests that, as observed in this study, learners with a more robust baseline understanding were better equipped to understand and apply the new information presented in the digital learning environment.

Prior knowledge must be considered when evaluating the effectiveness of gamification in educational settings. While previous research has highlighted the potential of gamification in enhancing engagement and motivation (Hamari et al., 2014; Sailer et al., 2017), this study's results suggest that this effect's efficacy may depend on the learner's initial knowledge level. Thus, learners with lower prior knowledge may require additional scaffolding or a more individualized implementation of game elements to benefit from gamified environments. Adaptive scaffolding in a gamified learning environment could enhance learners' experience by providing tailored support based on individual performance and prior knowledge levels (Faber et al., 2023). Consequently, in this study, adaptivity could have been used to improve performance and enhance engagement by offering more flexible tasks tailored to the users' needs.

The findings of the inferential analysis failed to replicate the findings of most previous research on the role of game elements in motivation and learning (Hamari et al., 2014; Sailer et al., 2017). However, other research also shows that the effect of gamification can be limited to specific factors (Böckle et al., 2020). The study reveals that the effect of gamification in promoting energy-saving behaviors highly depends on how the gamified elements are implemented. Moreover, the study highlights that different user types respond differently to gamified systems (Böckle et al., 2020). It is mentioned that gamification has potential but often fails to engage users or can even lead to adverse outcomes because of the overemphasis on extrinsic rewards that can lead to a decrease in intrinsic motivation (Seaborn & Fels, 2015). Hence, by emphasizing the way game elements are implemented in a digital learning environment and additionally making this environment more adaptive, it is more likely that engagement will increase as well.

The context dependency of gamification's effectiveness is supported by most previous research (Böckle et al., 2020; Faber et al., 2023; Seaborn & Fels, 2015). According to self-determination theory (Deci & Ryan, 1985), intrinsic motivation is driven by the satisfaction of the three fundamental needs (competence, autonomy, and relatedness). If these needs are not fulfilled, the user's engagement will not be increased, and hence, the learning outcomes will not improve. Hence, it needs to be further investigated how strong the game elements must be to fulfill these specific needs. The salience of game elements plays a crucial role here (Sailer et al., 2017). In this study, the game elements were integrated subtly, which may have decreased the effect on engagement.

It is interesting that despite the implementation of gamification, no significant difference in engagement or learning outcomes was observed across conditions. A likely explanation for these findings is that a one-size-fits-all gamified environment failed to consider the diverse needs of the learners, particularly concerning their prior knowledge levels and fundamental needs. This idea is further supported by the finding that adaptive scaffolding in games could solve these problems in previous studies (Faber et al., 2023). The results strongly imply that learners with lower prior knowledge might have needed more explicit guidance. In comparison, learners with higher prior knowledge could have been challenged further, preventing disengagement and boredom.

Study Limitations

There are multiple potential limitations concerning the results of the study. First, it is essential to mention that the sample could be biased. Due to the high participant dropout rate, the sample is small and may not represent the broader population. In addition to that, it is possible that the remaining people were more motivated or had a stronger interest in sustainability topics. This introduces the mortality bias, where the characteristics of participants who finished the study could differ significantly from those who dropped out. For example, participants who were less interested or had lower prior knowledge could be more likelier to leave the study. This could partly explain the lack of significant findings between groups, as those with higher prior knowledge may have been overrepresented. This is also supported by the fact that the sample includes mainly people who have obtained a higher education, which correlates positively with environmental knowledge, attitude, and behavior (Zsóska et al., 2013). Hence, these participants have high prior knowledge and a positive change in knowledge is more challenging to measure.

Another limitation is the design of the knowledge questionnaire. It was a self-designed questionnaire aimed to test knowledge acquired through the study session. Thus, the questions closely mirrored the content of the learning environment, which means it is possible that the participants simply recognized correct answers due to repeated exposure rather than demonstrating a deep understanding of the domain. Hence, knowledge acquisition might not be measured accurately. A validated knowledge test could give more accurate insights into how much new knowledge was acquired.

The last limitation concerns the measurement of engagement. The study relied on an obtrusive one-time measurement: a self-report questionnaire after the learning session. Even though the questionnaire is validated, the results might be biased because engagement was not measured in real-time while participants engaged in the learning environment. The retrospective nature of the assessment could bias the participants' perceptions. It is common that participants do not accurately remember their engagement after they have finished the tasks (Fuller et al., 2018). Hence, future studies should aim to gather real-time engagement data using unobtrusive methods such as log data or behavioral tracking.

Implications for Future Research

Future studies should address these limitations by testing a larger, more diverse sample to detect differences between the conditions accurately. In addition to that, it is essential that adaptive scaffolding is implemented in the digital learning environment. This could lead to decreased dropout rates for people with lower prior knowledge. Regarding knowledge acquisition, future research should use more generalized validated tests to assess participants learning outcomes. The learning environment has to be tailored to these specific tests without mirroring its content. In addition, engagement should be measured more unobtrusively in real-time during learning activities. For example, this can be done by using log files (Sharek & Wiebe, 2014). Lastly, a study design that includes multiple, shorter sessions could show more significant effects because engagement can be measured over time, and knowledge acquisition can be tested in multiple instances, providing deeper insights about the structure of these constructs.

This study opens possibilities to investigate further the effectiveness of gamification elements and, specifically, storytelling in the context of ESD. Even though the study could not find solid and significant findings related to the tested hypotheses, it still contributes by providing a well-researched and thoughtfully constructed design of a learning environment and innovative ideas that can be improved to continue with future research. Work must be done on implementing specific game elements because, as previous research also claims, gamification is not a universal instrument that leads to automatic improvement (Seaborn & Fels, 2015). Finding tools that give more control over single design elements is essential to enable more individualization in designing the conditions. Implementing adaptive elements to consider different states of prior knowledge is also important. As mentioned above, a change of the study setup with similar ideas can be used to do a more extended study with multiple measurements to investigate the potential effects further.

Conclusion

The findings of this study provide valuable insights into the potential and limitations of using game elements and isolated storytelling elements on engagement and knowledge acquisition in the context of Education for Sustainable Development. Despite the expected effects of gamification, such as increased engagement and knowledge acquisition, which could not be statistically supported, the results emphasize that these elements' effectiveness heavily depends on their design, implementation, and the learner's characteristics. A key takeaway from this research is the essential role of prior knowledge. Participants with higher prior knowledge showed stronger learning outcomes, suggesting that gamified digital learning environments must consider varying levels of prior knowledge. This highlights the importance of adaptive learning environments, where game mechanics can be tailored to the learner's specific needs, such as knowledge level and learning pace. Hence, future research and designers of digital learning environments should consider using adaptive scaffolding to ensure that gamification strategies are inclusive and beneficial for different types of learners. Despite the lack of significant results, this study contributes to ongoing research about educational methods in ESD. Building on the findings and insights can ensure that future gamified learning environments positively impact learners, which also leads to more sustainable behaviors.

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Appendix

Appendix 1

User Engagement Scale Short-Form

Q33 Now, you will evaluate your learning experience by answering the following questions. Please indicate your opinion of the statements on a scale from strongly disagree to strongly agree.

FAS1 I lost myself in this experience

- ○ Strongly disagree (1)
- ○ Somewhat disagree (2)
- ○ Neither agree nor disagree (3)
- ○ Somewhat agree (4)
- ○ Strongly agree (5)

FAS2 The time I spent using the sustainability game just slipped away

- ○ Strongly disagree (1)
- ○ Somewhat disagree (2)
- ○ Neither agree nor disagree (3)
- ○ Somewhat agree (4)
- ○ Strongly agree (5)

FAS3 I was absorbed in this experience.

- Strongly disagree (1)
- Somewhat disagree (2)
- Neither agree nor disagree (3)
- Somewhat agree (4)
- Strongly agree (5)

PUS1 I felt frustrated while using this sustainability game.

- Strongly disagree (1)
- Somewhat disagree (2)
- Neither agree nor disagree (3)
- Somewhat agree (4)
- Strongly agree (5)

PUS2 I found this sustainability game confusing to use.

- Strongly disagree (1)
- Somewhat disagree (2)
- Neither agree nor disagree (3)
- Somewhat agree (4)
- Strongly agree (5)

PUS3 Using this sustainability game was exhausting.

- ◯ Strongly disagree (1)
- ◯ Somewhat disagree (2)
- ◯ Neither agree nor disagree (3)
- ◯ Somewhat agree (4)
- ◯ Strongly agree (5)

AES1 This sustainability game was attractive.

- ◯ Strongly disagree (1)
- ◯ Somewhat disagree (2)
- ◯ Neither agree nor disagree (3)
- ◯ Somewhat agree (4)
- ◯ Strongly agree (5)

AES2 This sustainability game was aesthetically appealing.

- ◯ Strongly disagree (1)
- ◯ Somewhat disagree (2)
- ◯ Neither agree nor disagree (3)
- ◯ Somewhat agree (4)
- ◯ Strongly agree (5)

AES3 This sustainability game appealed to my senses.

- Strongly disagree (1)
- Somewhat disagree (2)
- Neither agree nor disagree (3)
- Somewhat agree (4)
- Strongly agree (5)

RWS1 Using the sustainability game was worthwhile.

- Strongly disagree (1)
- Somewhat disagree (2)
- Neither agree nor disagree (3)
- Somewhat agree (4)
- Strongly agree (5)

RWS2 My experience was rewarding.

- ◯ Strongly disagree (1)
- ◯ Somewhat disagree (2)
- ◯ Neither agree nor disagree (3)
- ◯ Somewhat agree (4)
- ◯ Strongly agree (5)

RWS3 I felt interested in this experience.

- ◯ Strongly disagree (1)
- ◯ Somewhat disagree (2)
- ◯ Neither agree nor disagree (3)
- ◯ Somewhat agree (4)
- ◯ Strongly agree (5)

End of Block: User Engagement Scale

Appendix 2

Questionnaire about Different Sustainability Topics

Which diet typically has the lowest overall environmental impact, considering factors such as greenhouse gas emissions and land use?

- Vegan (1)
- Pescetarian (2)
- Omnivore (3)
- Vegetarian (4)

Q52 Which of the following food items has the highest carbon footprint per kilogram produced?

- Beef (1)
- Chicken (2)
- Lentils (3)
- Apples (4)

Q53 What of the following is not a direct consequence of food production?

- Deforestation (1)
- Ozone layer depletion (2)
- Increased water usage (3)
- Greenhouse gas emissions (4)

Q54 What is not a benefit of recycling?

- ◯ Reduce consumption of resources (1)
- ◯ Minimization of waste sent to landfills (2)
- ◯ Decrease energy usage (3)
- ◯ Increases the cost of manufacturing products (4)

Q55 In which waste bin do receipts belong?

- ◯ Paper & Cardboard (1)
- ◯ Organic (2)
- ◯ Residual (3)
- ◯ Plastic, Metal and Drink Cartons (4)

Q56 Which of the following materials is least likely to be recyclable?

- ◯ Glass (1)
- ◯ Paper (2)
- ◯ Styrofoam (3)
- ◯ Aluminium (4)

Q57 What household change can most significantly reduce water usage?

- ○ Installing low-flow showerheads and faucets (1)
- ○ Using an older toilet model (2)
- ○ Taking baths instead of showers (3)
- ○ Washing dishes by hand instead of using a modern dishwasher (4)

Q58 How does conserving water benefit the environment? (multiple answers allowed!

- ▢ Reduces the energy required for water treatment and distribution (1)
- ▢ Protection of freshwater ecosystems (2)
- ▢ Enhances the aesthetic value of urban areas (3)
- ▢ Mitigates impacts of droughts and water shortages (4)

Q59 How much water does an average Dutch citizen use in a day?

- ○ 200l (1)
- ○ 120l (2)
- ○ 80l (3)
- ○ 40l (4)

Q60 What is the environmental benefit of using public transportation instead of a personal car?

- Reduces traffic congestion and lowers overall emissions (1)
- Increases commute time for individuals (2)
- Requires more infrastructure development (3)
- Increases individual carbon footprints (4)

Q61 Which mode of transportation has the smallest carbon footprint per passenger mile?

- private car (1)
- Bus (2)
- Airplane (3)
- Train (4)

---

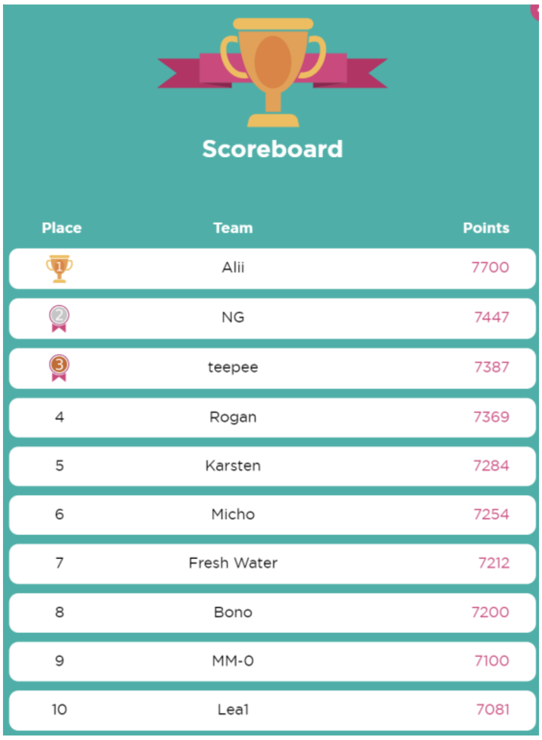
62 What are the average CO^2 emissions for an electric car per km?

- 91g CO^2 (1)
- 124g CO^2 (2)
- 47g CO^2 (3)
- 32g CO^2 (4)

End of Block: SK Post

Appendix 3

Leaderboard in the Learning Environment

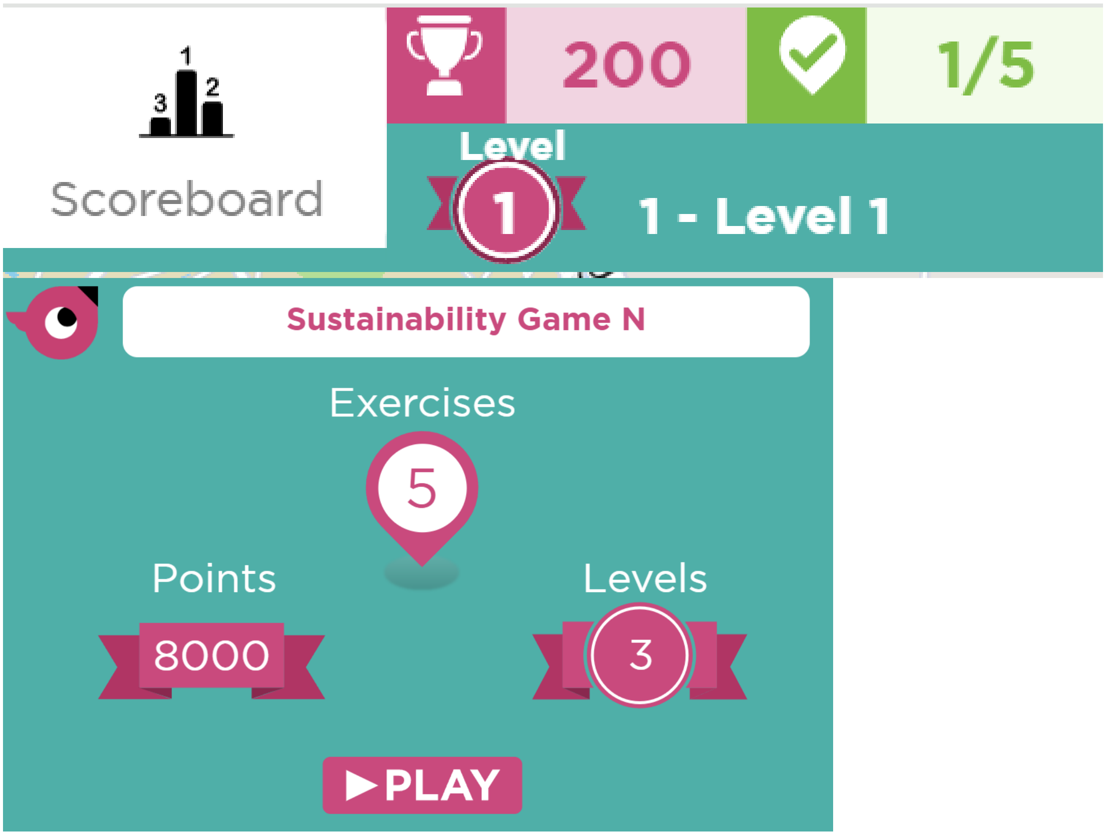


Scoreboard

Place	Team	Points
1	Alii	7700
2	NG	7447
3	teepee	7387
4	Rogan	7369
5	Karsten	7284
6	Micho	7254
7	Fresh Water	7212
8	Bono	7200
9	MM-O	7100
10	Leal	7081

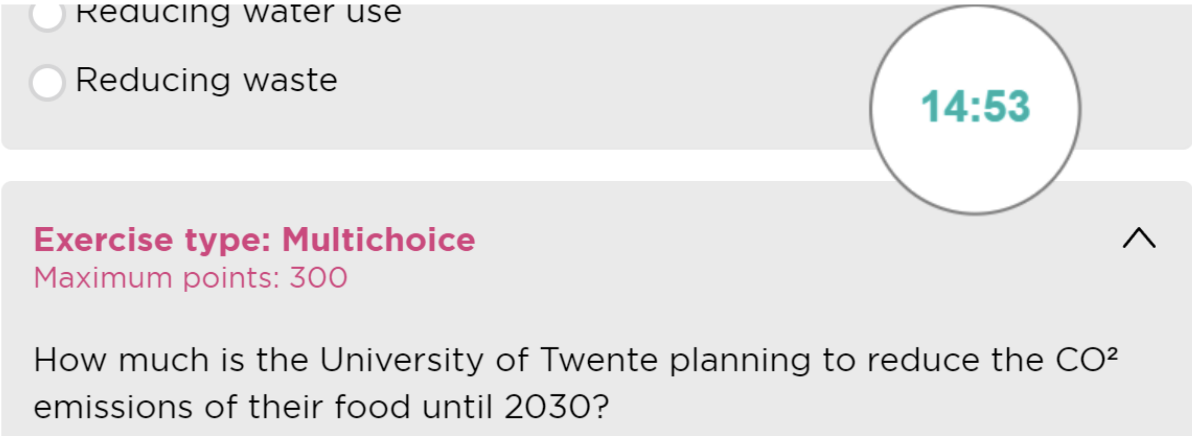
Appendix 4

Progress of Level and Points Displayed at the Top of the Page



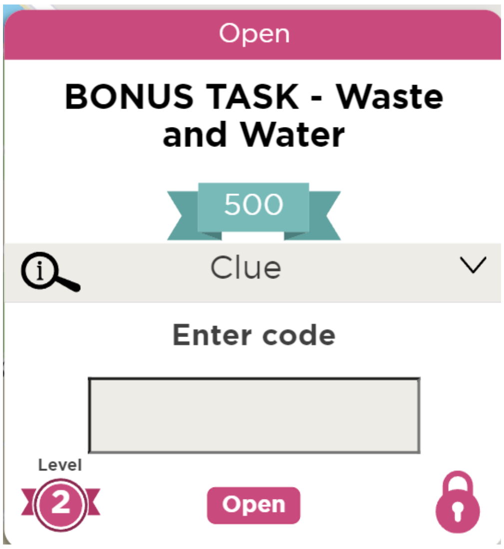
Appendix 5

Time Limit Displayed in each Task for the Gamification Conditions



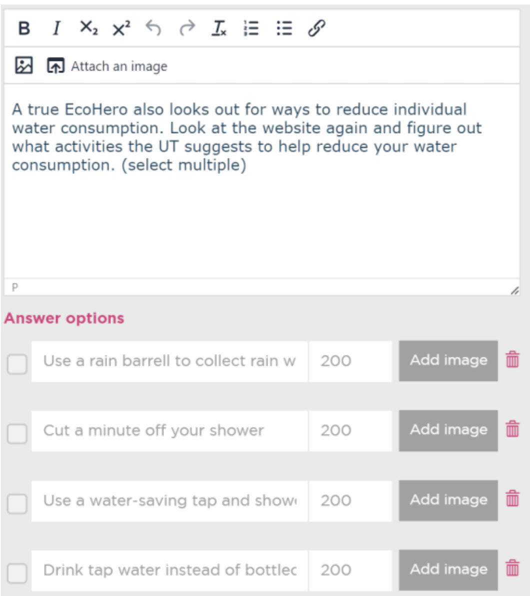
Appendix 6

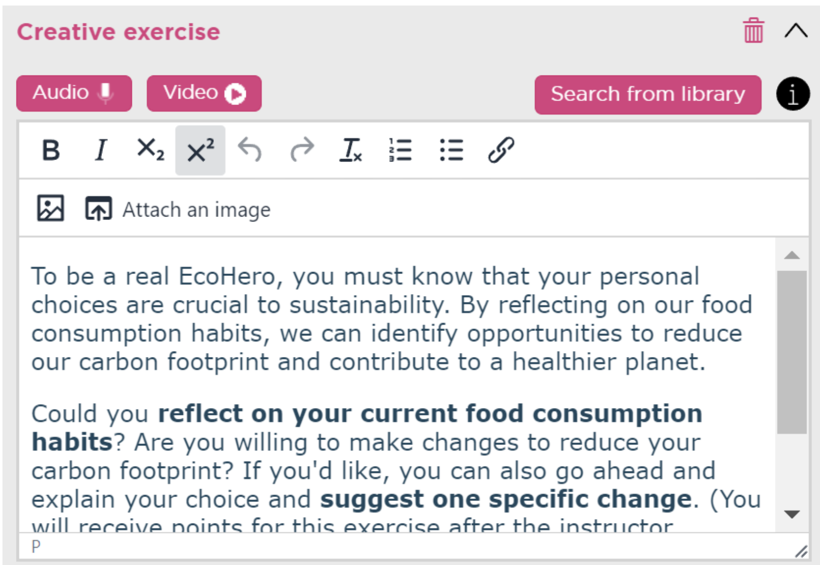
Bonus Task Locked by Password



Appendix 7

Examples of EcoHero Usage





Appendix 8

Example Task about Food

What we eat accounts for 20-30% of our carbon footprint!

Sustainable food consumption is a crucial component of reducing our environmental impact. Food production, **transportation, and disposal contribute significantly to greenhouse gas emissions, deforestation, and water usage**. We can help mitigate climate change and preserve natural resources by **choosing more sustainable food options**.

The University of Twente emphasizes reducing its carbon emissions derived from food and drinks.

Please take a look at the following website and discover how UT aims to make its food and drinks more sustainable: [Sustainability on Campus: Food & Drinks]

According to the sustainability plan displayed on the website, what is **not** a goal of the University when it comes to changing the food menu?

Appendix 9

Example Task about Transportation