Master's thesis

NTNU
Norwegian University of Science and Technology
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Department of Computer Science

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Gamified Environmental Education: Investigating the Impact of coralQuest on Learning Experience and Perceptions of Environmental Education for K-12 Students

Master's thesis in Informatics
Supervisor: Sofia Papavlasopoulou
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Abstract

Environmental education is crucial in addressing current environmental challenges and achieving the UN Sustainable Development Goals. However, traditional educational methods often fail to engage and motivate students effectively. To enhance student learning experiences, gamification has emerged as a promising approach. By incorporating game elements into educational settings, gamification creates an interactive learning environment that can boost motivation, enjoyment and improve learning outcomes. There is a lack of research on the intersection of gamification and environmental education for K-12 learners. Through the development of a gamified web application, coralQuest, this thesis investigated how the gamified application coralQuest affected the learning experience of K-12 students and how gamified software can affect students' perception of environmental education. The application was tested on 41 students from the 7th and 8th grades during a visit to The Science Centre in Trondheim. A mixed-method empirical study was utilized to gather quantitative and qualitative data through questionnaires, usage data, interviews, and observations.

The thesis has contributed insights into the impact of gamified environmental education and learning experience of K-12 students. The study identifies the impact of various game elements in coralQuest, highlighting the positive influence of a leaderboard on student enjoyment, engagement, and competitiveness. The incorporation of a pedagogical agent was found to enhance student enjoyment and facilitate learning, although some students perceive it as disruptive. The research indicates that coralQuest has the potential to improve traditional environmental education by enhancing students' enjoyment, engagement, perceived learning outcomes, and perceptions of environmental education. However, attention should be given to individual differences, as students with a pre-existing interest in environmental education and enjoyment of learning benefit more from the gamified application. Further research is needed to effectively engage initially uninterested students and promote positive attitudes toward environmental education. The findings emphasize the need for continuous research and improvement to design gamified learning applications that cater to diverse learners' needs and effectively engage them in environmental education.

Sammendrag

Miljøundervisning er avgjørende for å takle dagens miljøutfordringer og oppnå FNs bærekraftsmål. Imidlertid klarer tradisjonelle undervisningsmetoder ofte ikke å engasjere og motivere elevene effektivt. For å forbedre elevenes læringsopplevelser har spillifisering vist seg som et lovende virkemiddel. Ved å integrere spillelementer i undervisningssammenheng skapes et interaktivt læringsmiljø som kan øke motivasjonen til, og gleden ved å lære, samt forbedre læringsutbyttet. Det er mangel på forskning om samspillet mellom spillifisering og miljøundervisning for barne- og ungdomsskole elever. Gjennom utviklingen av en spillifisert nettapplikasjon, coralQuest, har denne studien undersøkt hvordan coralQuest påvirket læringsopplevelsen til barne- og ungdomsskole elever og hvordan spillifisert programvare kan påvirke elevenes oppfatning av miljøundervisning. Applikasjonen ble testet på 41 elever fra 7. og 8. trinn under et besøk på Vitensenteret i Trondheim. En empirisk studie ble brukt for å samle kvantitative og kvalitative data gjennom spørreskjemaer, bruksdata, intervjuer og observasjoner.

Denne studien har bidratt med innsikt i hvilken effekt spillifisert miljøundervisnings har på læringsopplevelsen til barne- og ungdomsskoleelever. Studien identifiserer effekten av ulike spillelementer i coralQuest. Spillelementet ledertavle viste seg å ha en påvirkning på elevenes engasjement og konkurranseinstinkt. Innføringen av en pedagogisk agent ble positivt mottatt og forbedret læringsutbyttet, selv om noen elever opplevde den som forstyrrende. Forskningen indikerer at coralQuest har potensiale til å forbedre tradisjonell miljøundervisning ved å forsterke elevenes glede i å lære, engasjement, oppfattede læringsresultater og oppfatninger om miljøundervisning. Imidlertid bør det tas hensyn til individuelle forskjeller, da elever med en forhåndsinteresse for miljøundervisning og iboende glede for å lære dro større nytte av den spillifiserte applikasjonen. Videre forskning er nødvendig for å finne løsninger som engasjerer elever som i utgangspunktet ikke har denne interessen og for å fremme positive holdninger til miljøundervisning. Funnene understreker behovet for videre forskning på hvordan utforming av spillifiserte læringsapplikasjoner kan imøtekomme ulike elevers behov og effektivt engasjere dem i miljøundervisning.

Acknowledgement

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We would also like to acknowledge and express our appreciation to Vitensenteret for providing inspiration in the development phase of coralQuest, and assistance with the user testing process. Additionally, we are grateful to the teachers and students who generously contributed their time to participate in this study.

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Contents

Figures

Tables

Acronyms

RQ Research question. 2, 7, 9, 11, 12, 14, 41, 65

SDT Self-Determination Theory. 8, 28, 66, 67

SLR Systematic literature review. 2, 8, 10, 11, 14, 19–21, 23, 25, 29, 30, 32, 67

STEM Science, Technology, Engineering and Mathematics. 10–12, 14, 17, 19–21

SUS System Usability Scale. 45, 46, 49, 52, 54–56, 65, 68, 69

XP Experience points. 24, 25, 31, 35, 40, 50, 51, 54, 60, 66

Chapter 1

Introduction

1.1 Problem Description

In light of the current environmental challenges, it is essential to learn about the environment and ways to live sustainably. Environmental education plays an important role in increasing awareness and knowledge about environmental issues, which can be a step toward achieving the UN Sustainable Development Goals. Environmental education focuses on raising awareness about environmental issues, sustainability, and the interconnections between humans and their surroundings [1, 2]. It is a core component in many school curricula across the world today. However, many schools today struggle with low student motivation and engagement, which can be attributed to traditional education being perceived as ineffective and tiresome by many students [3].

Consequently, there is a need to implement new, innovative ways to enhance student learning experiences. Research has shown that gamification can be a promising tool to achieve this[4]. By incorporating game elements into educational settings, educators can create a more interactive learning environment to boost students' motivation and improve their learning outcomes. Gamification has been found to enhance self-efficacy, increase students' sense of control over their learning and make learning more fun [5].

However, gamification has its own set of drawbacks that must be taken into account. While it can be an effective tool for enhancing student motivation and improving learning outcomes, it can also distract from the actual learning process [6] [7]. Additionally, gamification might lead to a competitive classroom culture where students are more focused on winning than on actual learning [6]. Therefore, it is important to carefully consider the potential negative consequences before implementing gamification in education.

1.2 Research Question and Aim

Due to a lack of research on how gamification can be used in environmental education for K-12 students, it is necessary to conduct further research in this area. As a part of the work with this thesis to investigate the topic further, a gamified application named coralQuest was developed. Findings from this research can contribute to new knowledge and insights in the field of gamification in environmental education for K-12 students and add on to the existing body of knowledge. The following research question will be discussed:

- Research question (RQ) 1: What effect does the gamified application coralQuest have on K-12 students' learning experience?
- RQ: How does coralQuest affect students' perceptions of environmental education?

1.3 Research Method

The research study began with an Systematic literature review (SLR) (Chapter 3), which provided insights into the current state of the art of the field and identified gaps in the research. Based on the gaps, RQs for this thesis were established. To answer the research questions, this study used a mixed-method approach. Pre- and post-tests were conducted to gather quantitative data before and after the participants engaged with the gamified application. Qualitative data was collected through interviews and observations in the same context. Furthermore, the usage data from the application provided both quantitative and qualitative insights.

1.4 Thesis Outline

This thesis is structured as follows: Chapter 2 provides the background and definitions of relevant terms. Chapter 3 contains the findings from a SLR, while Chapter 4 describes the design and development processes. Chapter 5 presents the research method, and Chapter 6 provides the results from the data analysis. Finally, Chapter 7 and Chapter 8 contain the discussion and conclusion, respectively.

Chapter 2

Background

This chapter presents relevant literature as well as definitions of concepts and terms that will be discussed throughout the thesis. The chapter concludes by positioning the current study.

2.1 Gamification and Gamified Education

There is a growing interest in using games in different contexts to increase engagement; this concept is called gamification and can be defined as implementing game elements, such as points, badges, and leaderboards, to non-game contexts [8]. Gamification has been implemented in many different industries, including e-commerce, finance, health care, and fitness [5], and this increasing trend also applies to education [5, 8]. Numerous studies have demonstrated the benefits of gamification in educational settings for students of different ages. For example, gamification can provide a *learning by failure* approach, which is common in games, enabling children to acquire knowledge and skills without the usual negative emotions and humiliation associated with traditional educational settings [9]. When game elements are implemented in a suitable way, it can result in multiple benefits such as increased motivation, engagement, and enjoyment among students [3, 5, 8]. Studies have shown that primary school children prefer gamified learning activities for subconscious learning [10]. Other examples include findings that show gamification concepts have the potential to improve children's grades [11], boost their motivation to learn science [12] and increase their satisfaction with homework [13]. However, game elements that are implemented in a non-suitable way could have negative effects on the children's learning experience [14]. Therefore, carefully designing gamification applications is crucial to ensure alignment with the learning objectives and needs of the users [14].

It's worth noting that studies on gamification have yielded conflicting results, with some experts arguing that positive outcomes may be due to novelty effects [15].

As a result, it's difficult to determine whether gamification is truly effective in a long-term perspective [5, 15]. While the incorporation of games and digital tools can enhance engagement and interactivity, there is a need to address the potential negative consequences. For instance, excessive screen time has been negatively associated with the development of physical and cognitive abilities in children [16]. Aspects such as over-reliance on extrinsic rewards or the potential for excessive competition can undermine the intended positive effects [6, 7] and addiction when a player excessively enjoys playing games [17]. Therefore, as stated by Hanus and Fox [7], it is crucial to critically assess existing solutions and consider their alignment with educational objectives.

The integration of digital tools in education for young students is a topic that sparks ongoing debates in today's society. The growing prominence of screens as a replacement for books raises significant questions regarding the potential advantages and disadvantages of incorporating technology in the classroom. A 2022 report by The Norwegian Directorate for Education and Training (UDIR) highlighted the positive effects of incorporating digital devices on a one-to-one basis, emphasizing the engagement it brought to students [18]. Conversely, there are those who advocate for schools to keep pace with the digitalization prevalent in society. The issue has garnered significant attention in national newspapers, and parliamentary leaders have initiated discussions to reevaluate the role of digital tools in education [19, 20]. While this thesis does not delve into the broader topic of digitalization in schools, it acknowledges its importance in the context of developing gamified software for K-12 education.

2.2 K-12 Students

The term *K-12* refers to the educational system and the thirteen years spanning from kindergarten to twelfth grade, also referred to as primary and secondary education. The target group of this study is students between the age of 12-14 who fall within the upper age range of primary school and the lower age range of secondary school in the Norwegian educational system.

2.3 Environmental Education

Environmental education is defined as a process where individuals explore environmental issues and participate in problem-solving activities to improve the environment as well as develop critical thinking skills [1, 2]. Learning about the environment and being aware of environmental issues can lead to an understanding of how to live more sustainably and make informed and responsible decisions that are beneficial for the environment. Environmental education can also play a significant role in building environmental awareness and responsible citizenship by addressing pressing global issues such as climate change, biodiversity loss, and exhaustion of resources [21].

United Nations Educational, Scientific and Cultural Organization (UNESCO) has declared that environmental education should be a core element in every school curriculum across the world by the end of 2025 [22]. It is also present in the Norwegian school curriculum for K-12 students [23]. It has been argued that successful learning in environmental education and making environmental education available to everyone can bring the world closer to reaching United Nations Sustainable Development Goals [22].

One emerging challenge in this regard is the concept of climate anxiety, which refers to the distress and fear experienced by individuals due to the overwhelming nature of climate change [24]. When educating future generations about climate change, educators must strike a delicate balance. On one hand, it's important to emphasize the significance and urgency of the topic, ensuring that students grasp the gravity of the situation. On the other hand, it is essential to avoid instilling fear or a sense of hopelessness that could hinder motivation and action. By adopting a sensitive and empathetic approach, educators can empower students to become proactive agents of change while providing them with the necessary tools and knowledge to address environmental challenges [25, 26]. Despite the complex nature of climate change, there are encouraging signs and positive trends, particularly among the younger generation. Today's youth are increasingly engaged in the fight against climate change and are actively seeking solutions to mitigate its effects. Their passion, commitment, and innovative thinking have propelled numerous climate action initiatives worldwide [27]. By integrating gamification and digital learning tools, educators can tap into the natural inclination of younger students to engage with technology and channel their enthusiasm toward addressing pressing global issues such as climate change.

2.4 Coral Reefs

The environmental focus of this study is coral reefs, one of the most biodiverse and important ecosystems on Earth [28]. Coral reefs cover less than one percent of the ocean floor yet support around a quarter of all ocean species. They support more complex food webs than any other place on the planet, which also humans benefit from. Coral reefs serve multiple purposes, including providing income and sustenance for millions of people globally. Moreover, they act as natural barriers, safeguarding coastlines against the destructive forces of waves and storms, thereby preventing potential loss of life, infrastructure damage, and erosion [29].

Coral reefs face multiple threats from human activities, such as overfishing, pollution, coastal development, and climate change [28]. Rising temperatures and ocean acidification cause coral bleaching. The loss of coral reefs has severe ecological, economic, and social consequences. It may result in the extinction of marine species that rely on corals for their survival, which in turn could disrupt the intricate food web that corals are a vital part of [30]. Given the significance of coral reefs, it is essential to raise awareness and encourage environmental educa-

tion about coral reefs and ocean conservation. Learning about coral reefs is a part of ocean literacy, which is defined as an understanding of the essential principles and fundamental concepts of the functioning of the ocean. It also includes being able to communicate about the ocean in a meaningful way and being able to make informed and responsible decisions regarding the ocean and its resources [31].

2.5 UN Sustainable Development Goals (SDG)

In 2015, the UN established the SDGs to address global challenges such as poverty, inequality, climate change, and education. The goals focus on attaining a sustainable future for humanity and the planet by 2030. SDG 4 (*Quality education*) is especially relevant for this research. Additionally, SDG 12 (*Responsible consumption and production*), SDG 13 (*Climate action*), and SDG 14 (*Life below water*) are also applicable. Within these goals, several targets are directly related to this study:

- Target 4.7: *Ensure that all learners acquire the knowledge and skills needed to promote sustainable development, including, among others, through education for sustainable development and sustainable lifestyles*.
- Target 4.a: *Build and upgrade education facilities that are child, disability, and gender sensitive and provide safe, non-violent, inclusive, and effective learning environments for all*.
- Target 12.8: *Ensure that people everywhere have the relevant information and awareness for sustainable development and lifestyles in harmony with nature*.
- Target 13.3: *Improve education, awareness-raising, and human and institutional capacity on climate change mitigation, adaptation, impact reduction, and early warning*.

The targets of SDG 14 *Life Below Water* are also highly relevant. The goal of SDG 14 aims to preserve the ocean, reduce pollution and ocean acidification, and protect ocean ecosystems. Coral reefs are a vital part of the marine ecosystem. Educating students on the significance of coral reefs and the urgency for protecting them can be a step towards achieving SDG 14.

Utilizing gamification in education can be a powerful way to achieve SDG 4's goal of providing quality education for all. Making education more engaging and interactive through gamification can help make it more accessible to a broader audience. Educating students about environmental issues through gamified applications can encourage them to take action to reduce their environmental impact and contribute towards a sustainable future.

2.6 Defining Learning Experience

Learning experience refers to any interaction or experience in which learning takes place. It entails more than just the acquisition of knowledge. The following section will present the terms and aspects used to discuss learning experience in this thesis and thereby be instrumental in answering the first RQ.

2.6.1 Enjoyment and Engagement

The concept of enjoyment in education has gained significant attention in recent years as educators recognize its profound impact on student engagement, motivation, and overall learning outcomes [32]. When students find enjoyment in their educational activities, they are more likely to be motivated, actively participate, and persist in their efforts to understand and master the subject matter. Moreover, enjoyment enhances students' cognitive processing, memory retention, and creative thinking abilities, leading to deeper and more meaningful learning experiences [32, 33]. This is exemplified in the study conducted by Wommer *et al.* [34], where 89.47% of the participants reported having enjoyed the game, which subsequently resulted in an interest in playing again. Sweetser and Wyeth [35] suggest that player enjoyment is crucial for digital games, implying that if a player does not enjoy a game, they will not play it [35].

Engagement can be defined as the simultaneous experience of increased concentration, interest, and enjoyment in the task at hand [36] and has been a topic of interest within the field of education for a long time [17]. Flow theory refers to the optimal state of engagement and immersion experienced by students in gamified education. According to this theory, students are more likely to achieve a state of flow when the challenges presented to them match their skill level [35]. In gamified education, this means designing educational activities that balance difficulty and the learner's abilities. When students are in a state of flow, they are fully immersed in the learning process, experiencing heightened focus, enjoyment, and personal growth [17, 35]. In the study by Cheng *et al.* [37], the gamified activity showed an increased level of flow among the participants, and according to the data collected by Zainuddin *et al.* [38], the participants in the study found gamified e-quizzes engaging. Due to the multiple benefits of being in a state of flow, it is important to consider how flow can be achieved when designing a gamified application.

2.6.2 Motivation

Motivation refers to the mental or emotional state that arouses an individual's behavioral or psychological change and has been described as one of the most important factors that can influence the success of gamification [17]. Motivation can be divided into two types: intrinsic and extrinsic motivation. The individual's curiosity or interest causes intrinsic motivation, while extrinsic motivation is in-

fluenced by external factors such as rewards or pressure [39]. When it comes to motivation, there are various theories to consider. One is the Self-Determination Theory (SDT), which suggests that a person's motivation is shaped by their surroundings, such as social and cultural factors [39]. This theory revolves around three main concepts: individuals believing they have control over their actions and outcomes, feeling confident in their ability to complete tasks, and having a sense of belonging or connection with others. In learning scenarios, these aspects can be emphasized by creating a sense of community or offering various learning options to the user.

A systematic review conducted by Mohammed and Ozdamli [40] explored the motivational effects of gamification apps in education. The study identified several key components that were particularly effective in motivating students to engage and actively participate in their learning activities. These components included points, levels, badges, leaderboards, and feedback. Each of these elements can be connected to the three concepts of SDT. Points, levels, and badges contribute to a sense of competence and mastery, fostering intrinsic motivation. Well-implemented feedback mechanisms help students build confidence in their abilities and enhance their self-efficacy. Leaderboards create a sense of relatedness and connection with others, encouraging social interaction and engagement. By incorporating these gamification elements, gamified applications can harness the power of motivation and create an engaging learning environment that promotes active participation and improved learning outcomes [40].

2.6.3 Perceived Learning Outcome

In education, learning outcome is often measured through tests to see what a student has learned. However, this is often time-consuming and focuses solely on the knowledge acquisition of the students. In this research, perceived learning outcome is obtained through self-reported measures.

Examining the perceived learning outcomes of K-12 students can capture their perspectives on the value and relevance of what they have learned in a quick and effective way. It can also provide a holistic understanding of learning outcomes by allowing the students to reflect upon their own learning process and thereby give an indication of what their actual learning outcome is [41].

An extensive meta-analysis conducted by Bai *et al.* [42] in 2020 found an overall significant medium effect size favoring gamification over learning without gamification. This is also found in many of the studies included in the SLR part of this thesis as well; Mead *et al.* [43] found a significant increase in learning outcomes, and Tsai *et al.* [44] also reported better learning outcome of scientific competencies in students who used a gamified application than those who learned via traditional teaching. However, findings connected to learning outcomes have contradicted, with some studies reporting negative effects, specifically when competition is involved [6].

2.7 Defining Perceptions of Environmental Education

The following section will present the terms and aspects used to discuss perceptions of environmental education in this thesis and thereby be crucial in answering the second RQ.

2.7.1 Interest

Interest can be described as an experience where an individual momentarily becomes captivated by an object or topic; this is also known as *situational interest*. The experience can often lead to a feeling that the object or topic is enjoyable; this can foster intrinsic curiosity and a desire to explore it further and learn more about it over time; this is known as *individual interest* [45].

Interest is important in the context of this thesis, as it has been shown that interested students tend to persist longer at learning new tasks; they spend more time studying, read more deeply and remember more of what they have read. They even tend to achieve better grades than their peers who lack this interest [46]. Another important aspect is that, in a long-term perspective, interest can motivate individuals to seek out new things [47], which is beneficial when teaching students about environmental education. If the students become interested in the subject of environmental education, it can facilitate for them to further study and learn more about the topic.

2.7.2 Attitude

Attitude refers to an individual's learned inclination to react positively or negatively toward an object, such as a situation, a concept, or a person [48]. According to Kind *et al.* [49], attitudes involve judging something along emotional dimensions, such as determining if it is good or bad, harmful or beneficial, pleasant or unpleasant, and important or unimportant.

Previous research has reported correlations between environmental attitudes and knowledge. The findings indicated that a higher level of knowledge positively affected students' attitudes towards the environment [50]. Research has also found indications that attitudes can predict behavior [51]. For instance, individuals' attitudes towards the environment were shown to affect their willingness to make personal changes to reduce climate footprint [52].

These findings highlight the importance of fostering positive environmental attitudes, as they suggest that doing so can be a key factor in promoting environmentally friendly behavior and enhancing individuals' knowledge about the environment.

2.8 Positioning the Current Study

An SLR conducted as a part of the preparatory project in the fall of 2022 provided an overview of findings from previous literature in the field. This SLR examined the use of gamification in both Science, Technology, Engineering and Mathematics (STEM) subjects and environmental education. Common game elements and design principles were identified, and the findings showed contradicting results on different aspects of the student learning experience. Therefore, there is a need to further investigate this topic.

Gamified applications that educate students on the environment can encourage them to take action to reduce their environmental impact and contribute to a sustainable future. Therefore, it is crucial to carefully consider the learning objectives and needs of the users when designing gamified applications.

This background chapter, along with the results from the conducted SLR (Chapter 3), presents a fraction of related work in the field. The findings, as well as related game theory, serve as the foundation for the development of the coralQuest application. The application is examined through an empirical research study that contributes to the existing body of knowledge of gamified environmental education for K-12 students. This is done by providing insights into how the gamified software affects students' learning experiences and perceptions of environmental education.

Chapter 3

Systematic Literature Review

Prior to the master thesis, an SLR was conducted to get an overview of the currently available research on the topic of gamification for K-12 students in STEM and environmental education. Among the existing literature in the field, research gaps were discovered. A total of 21 papers were selected. The findings and results from the selected papers created the foundation for this thesis and will be presented in this chapter. As a disclaimer, the contents of this chapter were submitted as part of the preparatory project by Motland [53] in the fall of 2022.

3.1 Research Method

To comprehensively explore the existing literature on the topic and identify potential research gaps, an SLR was conducted following the principles set forth by Kitchenham [54]. The process of developing the SLR included several steps. First, research questions were defined. Then, a search string and appropriate databases to query were determined. Once the papers were retrieved from the databases, inclusion, exclusion, and quality criteria were applied to select the most suitable papers. Ultimately, data extraction was carried out to gather relevant information from the selected papers.

3.1.1 Research Questions

The following were chosen as research questions for the SLR:

- **RQ 1:** What is the state-of-the-art of gamified learning applications for young learners with special reference to STEM subjects and environmental education?
- **RQ 2:** How can the use of gamified applications affect students' knowledge, attitude, and awareness towards the environment?

3.1.2 Data Sources and Search Strategy

To maximize the retrieval of relevant papers, a combination of four distinct search engines, namely Scopus [1], ERIC, Web Of Science [2], and the ACM Digital Library [3], was employed. The final search string utilized across these platforms was:

("gamification" OR "gamified" OR "game") AND ("game element" OR "gamified element*" OR "gamification element*" OR "gamification concept*") AND ("children*" OR "kids*" OR "students" OR "K-12" OR "K12") AND ("learning" OR "teaching" OR "education") AND ("environmental science*" OR "environmental education" OR "sustainable development" OR "Education for Sustainable Development" OR "ESD" OR "natural science*" OR "STEM" OR "STEAM" OR "physics" OR "chemistry" OR "Environmental awareness" OR "biology")*

In total, this resulted in 963 papers.

3.1.3 Study Selection

The papers were systematically organized within the Zotero[4] reference manager. Upon eliminating any duplicated entries, a thorough examination of titles and abstracts was conducted to assess their relevance. Subsequently, a set of predetermined criteria was applied to identify the papers that could effectively address the RQ's.

Inclusion Criteria

- Papers written in English.
- Papers published within the last five years.
- Papers focusing on STEM education and environmental education specifically for K-12 students.

Exclusion Criteria

- Papers that are behind a paywall or require a subscription for full access.
- Papers pertaining to analog gamification, including gamified classrooms, card, and board games.
- Papers that explore the use of student game-making tools (e.g., Scratch [5]) where the primary focus revolves around students designing and building games.

[1] https://www.scopus.com/
[2] https://www.webofscience.com/
[3] https://dl.acm.org/
[4] https://zotero.org/
[5] https://scratch.mit.edu/

Quality Assessment Criteria

- Papers must be peer-reviewed.
- Selected papers must be empirical or experimental in nature.
- Papers that are classified as work-in-progress or preliminary findings are excluded.
- The selected papers must clearly define the age group and size of the sample group of participants in the study.

During the quality assessment process, the inclusion and exclusion criteria were reevaluated to ensure that only papers that met the criteria were included. As a result of this thorough evaluation, a final selection of 21 papers was made. Figure 3.1 illustrates the step-by-step selection process.

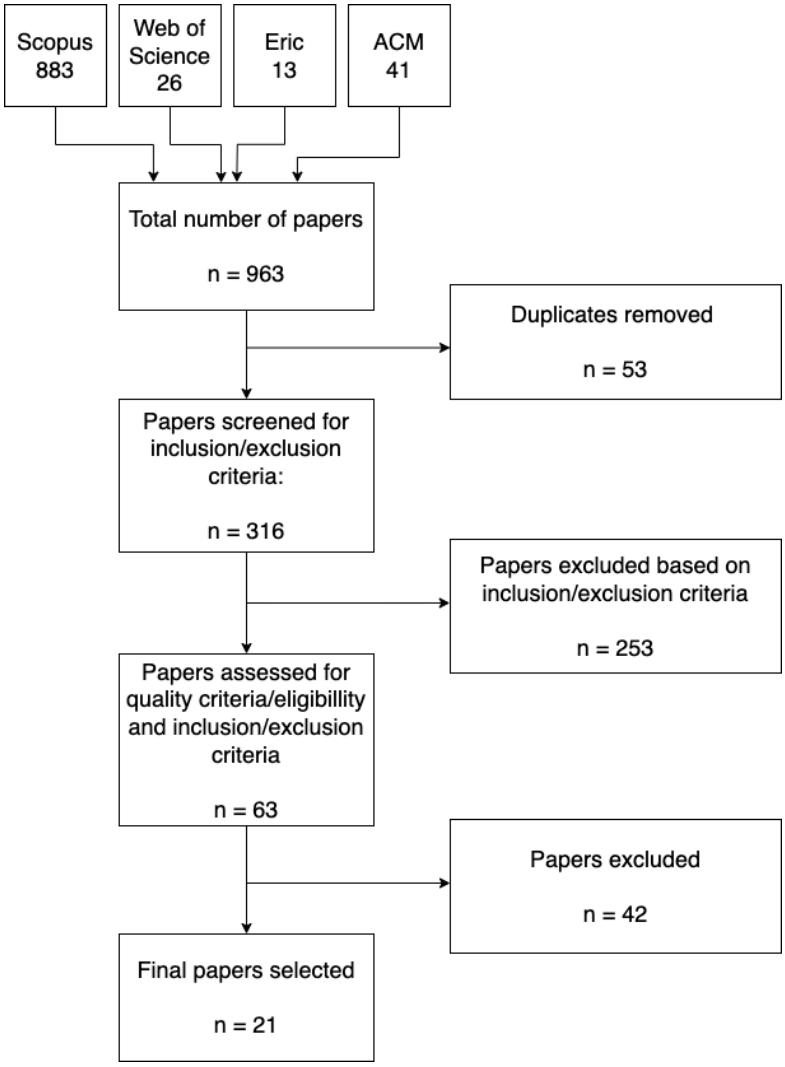


Figure 3.1: Study selection process

3.1.4 Data Extraction

To systematically organize and categorize data from the selected papers, a data extraction table was devised. Following the guidelines outlined by Kitchenham [54], the data extraction table was designed to capture all the essential information required to address the research questions. In addition to bibliographic reference details, the table encompassed demographics, methodology, and data pertaining to relevant gamified applications. This included information about game elements, themes, and aspects such as motivation, learning outcomes, and student satisfaction. Furthermore, the main findings derived from each paper were also extracted and recorded in the table.

3.2 Synthesized Results

This section will present the synthesized findings obtained from the SLR that are directly relevant to each of the RQ's.

3.2.1 RQ 1: Overview of State of the Art

This section presents the applications mentioned and studied in the papers included in the SLR. The applications presented are related to environmental education, either due to a focus on environmental issues, sustainable living, or teaching about natural sciences and the environment around us. Table 3.1 presents an overview of all the papers included in the SLR.

Gamified Education

The majority of the papers included in the SLR were centered around environmental education, accounting for 16 out of the total. Moreover, studies related to the gamification of STEM subjects for K-12 students were also included due to their potential contribution to addressing the RQ's. It is important to acknowledge that environmental education is a broad term [2]. Consequently, the selected papers cover a wide range of topics. Additionally, it is worth noting that many of the papers discuss multiple subjects simultaneously. In summary, the topics covered in the literature include learning about carbon footprint, ocean literacy, recycling, ecology, entomology, natural science topics such as biology, physics, and natural phenomena and natural disasters. These topics collectively contribute to knowledge and an understanding of the Earth and the environment. Furthermore, some of the studies specifically aim to raise awareness about the direct impacts of climate change and foster sustainable behaviors, including waste management, recycling, and carbon footprint reduction.

Among the papers included in the selection, a combination of game-based learning and gamification applications were represented. Specifically, 15 papers were centered around gamification, while 6 papers focused on game-based learning.

No.	Author(s)	Educational level	Subject	Context
1.	Priyadarshini *et al.* [55]	Middle school	Carboon footprint	Web game-based application ("Carbon Warrior")
2.	Leitão *et al.* [56]	Middle school	Ocean Literacy & Recycling	Mobile gamified application ("Ocean Literacy")
3.	Leitão *et al.* [6]	Middle school	Ocean Literacy & Recycling	Mobile gamified application ("Ocean Literacy")
4.	Andrade *et al.* [57]	Middle school	Physics (electricity)	("Graasp online learning platform") tool
5.	Sánchez-Rivas *et al.* [58]	Primary school	Natural Sciences	Gamfied course and examination (Trival quiz)
6.	Mead *et al.* [43]	High school	History of life on Earth, biology, ecology, geology	Virtual field trip-based learning application ("Surviving Extinction")
7.	Jawad [59]	High school	Programming	Web-based gamified application ("Code Genie")
8.	Moral-Sánchez *et al.* [60]	High school	Geometry	Web-based gamified course using Classcraft and Edmodo tools
9.	Wommer *et al.* [34]	Middle school	Entomology	Gamfied mobile-based application ("InsectsGO")
10.	Cheng *et al.* [37]	Middle school	Physics	Gamified science inquiry activity with tool ("Power up 3.0")
11.	Ortiz *et al.* [61]	High school	Geometry	Mobile Game-based math application for ("MathyFighty")
12.	Ricoy and Sánchez-Martínez [62]	Primary school	Environmental awareness	Different web-based gamification applications
13.	Sánchez and Cano [63]	High school	Natural sciences	Gamified model in science course through ("Google Classroom")
14.	Tsai *et al.* [44]	Primary school	Marine education carbon footprint	Game based learning by use of learning platform ("E-game")
15.	Ramli *et al.* [64]	Middle school	Biology	Mobile gamification application ("m-BioP")
16.	Hobbs *et al.* [65]	Primary school	Environmental science	Web-based game-based application using Minecraft in education ("Science Hunters")
17.	Alsadoon *et al.* [66]	Middle school	Programming	Gamified online learning tool ("Saudi National Online e-Learning Platform")
18.	Ying *et al.* [67]	Primary school	Solar system	Mobile gamification application ("SoLAR Kid")
19.	Garneli *et al.* [68]	Middle school	Physics	Web game-based learning application ("Adventure of Sciences")
20.	Zainuddin *et al.* [38]	High school	Science class Natural disasters	Web-based learning through quiz, use of tools ("Quizziz") and ("iSpring learn LMS")
21.	Jones *et al.* [69]	High school	Biology	Web-based learning through platform ("Kahoot!")

Table 3.1: Selected papers

Existing Applications

The following paragraphs will present applications from the papers included in the SLR grouped by the theme and subject the application falls under.

Carbon Footprint
Two studies included knowledge of carbon footprint and the outcome of carbon emissions.

Carbon Warrior [55] is an educational game that teaches middle school students about minimizing their carbon footprint. The game presents everyday scenarios where players have to choose the most sustainable option to reduce their carbon footprint. A progress bar called "warmth" indicates global warming and increases if non-sustainable choices are made. The game offers hints and feedback to help players learn from their choices and apply that knowledge in their daily lives. Fifteen middle school students tested the game and provided qualitative feedback. Some terms were confusing, so including images was suggested. While there were some issues with understanding game elements like the warmth meter and point calculation, the game was generally found easy to use.

E-game is a digital learning platform with themed islands, including Science Island [44]. The application's theme is carbon dioxide entering seawater and its effects on the ocean and shellfish. Players must catch carbon dioxide to prevent the shellfish population from shrinking. The study aims to educate primary school students on carbon emissions and ocean acidification. 69 students participated, and the experimental group using E-game had higher learning outcomes than the control group. High- and low-performing students reported positive perceptions and attitudes toward the game. The learning outcome was positive for all student types.

Recycling
Three studies focused on recycling, among other learning objectives. Two of these are about how waste affects life underwater, while the third focuses on different sustainable activities such as recycling, reusing items, reducing waste, and recovering broken things.

Ocean Literacy is presented in two papers, [6] and [56], and is a gamified application that teaches middle school students about recycling and pollution's effects on ocean life. Players sort waste in the correct bins while keeping the seawater and fish healthy. Points, badges, and leaderboards were used to test motivation and learning outcomes. Data from 98 students shows the app's effectiveness. The app increased motivation, and the combined PBL (points, badges, and leaderboard combined) triad was most effective in terms of learning. The leaderboard alone had a negative effect on learning outcomes.

Interactive digital applications [62] were used in a Spanish primary school class

to teach students about the 4R's: reduce, reuse, recycle, and recover. Various resources, such as tablets, gamified apps, and digital tools, were used to learn about waste management and the environment. Both teachers and students participated in the study and reported positive effects, such as increased motivation, improved attention, and better problem-solving skills. It was also found that environmental responsibility increased among students who began to apply the guidelines they learned at school and at home.

Life on earth, ecology, entomology, and natural phenomena
Environmental education involves understanding the world around us, which includes gaining knowledge about life on Earth and natural phenomena. Exploring these concepts is essential in order to understand our surroundings. Three of the papers presented applications related to this theme.

Insect GO [34] is a gamified activity that teaches middle school students about insects by capturing real insect images with their phones, gaining points and reaching new levels. A study with 21 middle school students showed that the application improved their learning of entomology, but 40-50% still struggled with basic questions. Student satisfaction was high, with many playing after school, and 89.47% wanting to play again. The activity promoted engagement and motivation to learn, although some students did not participate due to a fear of insects.

Surviving Extinction [43] is a gamified virtual field trip application that teaches middle school students about ecology, biology, geology, and vertebrate evolution over the past 350 million years. Using Augmented Reality (AR), students explore different environments through the perspective of an animal and answer questions to earn coins. Pre- and post-tests showed an increase in learning outcomes, and participants reported high satisfaction. However, some usability issues with the user interface and navigation were addressed.

Science Hunters [65] is a Minecraft-based game that teaches children about natural phenomena such as volcanoes and plant growth. It can be used as a tool to make learning more engaging for students from kindergarten to high school. In this study the students explore and solve problems related to an increasing population on earth through playing Minecraft. Feedback from the players was overall positive.

Other natural science subjects, biology, and physics
Subjects such as biology and physics are a part of STEM and are also important in explaining concepts of the earth and the environment. Therefore, studies from these disciplines were included as well.

m-BioP [64] is a mobile gamified application for teaching animal developmental biology to secondary school students. It features AR, 2D and 3D models, quizzes, as well as a score system. The prototype was developed based on interviews with

students struggling to understand the subject, and usability was evaluated by experts, resulting in some necessary changes.

Graasp online learning platform [57] was gamified using points, badges, and leaderboard in three versions of an online electricity module for middle school physics students. The experiment involved 199 students from two schools, showing positive impact on usability, engagement, and learning performance, but no significant increase in motivation. The prototype using points had the best engagement score.

Game Elements

Figure 3.2 gives an overview of the game elements used in the various studies and their frequency. In addition to the displayed game elements, all the gamified applications incorporated some form of challenge, such as learning assessments, tasks, quizzes, coding exercises, or science activities. The most frequently used game element across all studies were points, utilized in 18 studies. Followed by badges, levels, feedback, and leaderboard, respectively.

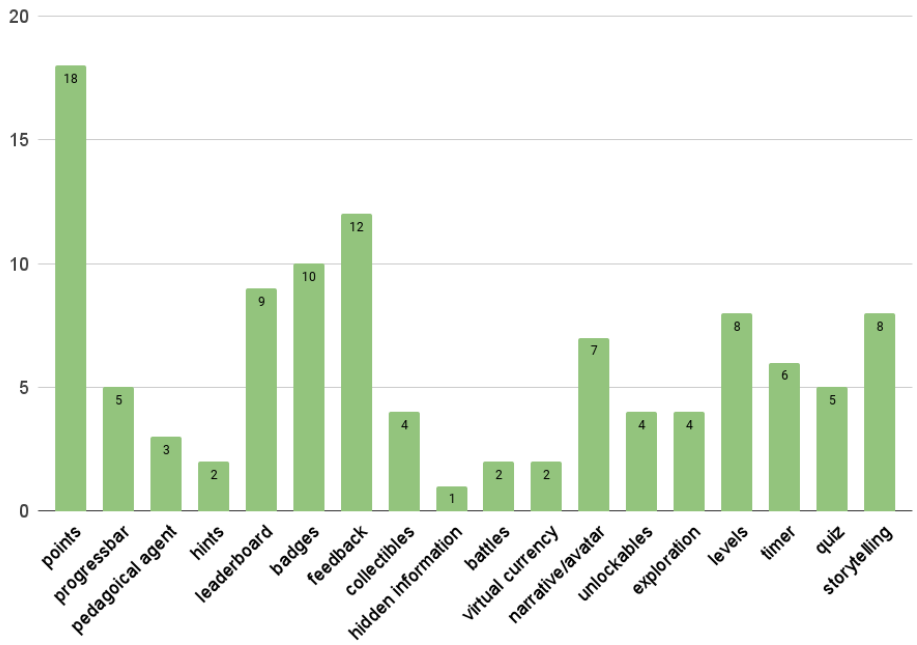


Figure 3.2: Frequency of game elements used across the selected studies

An important game element, rewards, is not listed in Figure 3.2, as rewards is often a collective term. Among the papers included the identified game elements that represent rewards includes virtual currency, points, badges, positive feedback, collectibles, and unlocking new levels and assets.

Various game elements can be utilized to convey immediate feedback, in addition to the specific element known as "feedback" shown in the figure. These elements include pedagogical agents, progress bars, personal scoreboards, and integration within the game's storyline. However, as the implementation details regarding immediate feedback were not consistently explained across the included studies, it is not represented as a distinct element in Figure 3.2.

3.2.2 RQ 2: The Impacts of Gamified Applications

This section aims at answering the second research question of this SLR. *How can the use of gamified applications affect students' knowledge, attitude, and awareness towards the environment?*

Effects of gamified environment

The measures and results that the various research emphasize are summarized in Table 3.2. Learning outcome was the most frequently used measure across the studies, followed by motivation, engagement, and user satisfaction. The least discussed effect was pro-environmental behavior, with only three papers. Overall, the studies reported a high degree of student satisfaction and motivation among the participants. The effects on learning outcomes are contradicting, some studies report positive results on learning outcomes, while others report non-significant results.

What is measured	**Studies**
Motivation	[56], [57], [58], [60], [34], [61], [63], [65], [66]
Learning outcome	[6], [57], [58], [43], [60], [34], [37], [62], [63], [44], [65], [66], [67],[38]
Engagement	[56], [57], [34], [37], [63], [65], [38], [69]
Usability	[55], [57], [43], [59], [64], [67], [68]
Pro-environmental behavior	[56], [6], [62]
Satisfaction	[58], [43], [37], [61], [44], [65], [66], [38]
Interest	[43], [34], [61], [69]

Table 3.2: Aspects measured in selected papers

3.3 Discussion

This section will discuss the findings of the SLR with a focus on investigating how the use of gamification in STEM and environmental education affects K-12 students.

3.3.1 State of the Art

This SLR examines the effectiveness of gamified learning tools for K-12 students in environmental education and STEM subjects. The review found that most studies on gamification yielded positive results for student motivation and enjoyment.

The gamified applications identified in the SLR used various game elements, with points, leaderboards, and badges being the most popular. Studies showed that these elements had positive effects on student experience and motivation, with students finding games more fun when these elements were present [6, 38, 69]. However, the leaderboard game element, which led to competitiveness, had a negative effect on learning outcomes in some studies, while points and badges increased learning outcomes in others [6]. The use of a leaderboard in *Ocean Literacy* had a positive effect on students' motivation to recycle [56]. Points, badges, and leaderboards have also been shown to have a positive outcome on student engagement and user excitement in multiple papers [6, 56, 57]. This indicates that points and badges can be useful elements for motivating and encouraging students in learning, which can eventually lead to higher learning achievements.

Although gamification and game-based learning can be effective, it is crucial to recognize that there is no universally applicable approach. Individual variations in learning styles and preferences, as well as the diverse nature of student populations, require personalized approaches to gamification. Customization and the use of pedagogical agents were found to enhance the player's experience and motivation. Notably, several studies suggest that the incorporation of avatars and customization options increases player experience, enjoyment, and motivation [60, 61]. Additionally, the implementation of a pedagogical agent, which offers immediate feedback and guidance to students, can serve as both a teacher and a friendly assistant. While the use of pedagogical agents was not prevalent in the papers examined in the SLR, the results from the three studies that employed them were consistently positive [55, 67, 68].

A significant number of the studies included in the analysis employed levels as a game element. The incorporation of difficulty levels in gamified learning tools has been shown to have a positive impact on learning outcomes for both high-achieving and low-achieving students. This finding aligns with Malone's heuristics for designing enjoyable educational games, where the inclusion of multiple difficulty levels enhances user enjoyment [70].

3.3.2 Impacts of Gamified Applications

Although many studies in environmental education focus on nature and environmental phenomena, few researchers have addressed direct actions for living sustainably. However, it is important to note that learning about the environment can foster pro-environmental attitudes making students more environmentally aware [2, 21]. To avoid a pessimistic outlook on the future, it's essential to emphasize

the positive aspects of nature in addition to teaching sustainable actions [24].

Gamification and game-based learning have demonstrated promising outcomes in motivating students to learn about and develop a sense of care for the environment. Notably, the implementation of gamified approaches, such as Ocean Literacy, has been associated with improvements in students' recycling competencies and knowledge about marine wildlife [6, 56]. Furthermore, another study reported increased environmentally friendly behavior, such as reducing waste and saving water and electricity, among students who participated in a gamified environmental project [58]. Since only a few papers focused on pro-environmental outcomes, further research is needed to investigate the long-term effects of gamified environmental education on behavior. It's also important to consider the novelty effect in these studies and determine if gamification remains effective in the long term.

3.4 Conclusion

A substantial number of papers were considered during this SLR. It revealed a lack of recent studies on gamified environmental education for K-12 students and how it affects their environmental awareness. Therefore, more research in this area should be conducted. Studies in the field have reported generally positive results, indicating that gamification can increase knowledge, attitude, and awareness of the environment. Results regarding learning outcome in gamified STEM subjects and environmental education shows contradicting results; some claim gamification and game-based learning are effective tools for promoting student learning, while other see no significant increase in students' achievements.

More research is needed to understand the effects of gamified environmental education on students' perceptions of learning about the environment, as well as to further investigate the effects of including specific game elements, such as a pedagogical agent, in this context.

Chapter 4

Design And Development

This chapter presents the web application coralQuest, which was developed as part of this thesis. The chapter is structured by presenting the application requirements, the design and development process, and then the architecture and implementation. The coralQuest application can be accessed at `https://coral-reef-awareness.web.app/`, and the source code can be obtained from `https://github.com/JulieHM/coralQuest`.

4.1 Requirements

Before starting the development process, functional and non-functional requirements were defined. The functional requirements specify features, while the non-functional address requirements related to usability, performance, reliability, compatibility, and maintainability. This process of establishing such requirements is vital for effective resource allocation and task prioritization, and it enhances communication and collaboration among the developers [71].

4.1.1 Functional Requirements

The functional requirements were established based on relevant gamification- and game-theory literature and findings from the SLR. The requirements were prioritized based on the MoSCoW prioritization method [72]. This method groups the different requirements into categories of importance. Requirements that the application must satisfy in order to be considered a minimum viable product are classified as "*must have*" requirements. Requirements in the "*should have*" category are important and should be satisfied but are not vital. Lastly, requirements in the "*could have*" category are desirable to implement if there is enough time but are not as important as the "*should have*" requirements. The requirements are presented in Table 4.1, 4.2 and 4.3 below.

Must Have Requirements

ID	Requirement
FR1	The user must be able to log in to the application
FR2	The user must be able to select an avatar and avatar name
FR3	The user must be able to navigate to different quests in the app, diving-quest and quiz
FR4	The user must be able to see correct and wrong answers when taking a quiz
FR5	The user must be able to view embedded Google Earth Maps in the application during the diving quest
FR6	The user should get guidance from a pedagogical agent
FR7	The user must be able to earn virtual currency as a reward for completing a quest
FR8	The user must be able to use virtual currency to buy corals
FR9	The application must store data in a database so that user progress will not get lost
FR10	The application must be able to collect usage data

Table 4.1: Must have requirements

Should Have Requirements

ID	Requirement
FR11	The user should be able to earn Experience points (XP) and increase their level
FR12	The user should be able to see how they are progressing in the game compared to others in a leaderboard
FR13	The user should be able to view a progress bar indicating how much XP is needed to reach the next level
FR14	The user should be able to play quizzes of different difficulty levels

Table 4.2: Should have requirements

Could Have Requirements

ID	Requirement
FR15	The user could be able to unlock new quizzes as they increase in level
FR16	The user could be able to unlock certain corals as they reach a certain level
FR17	The application could assign users to groups belonging to different leaderboards
FR18	The user could be able to see animated animals swimming among the corals bought
FR19	The user could be able to view achievements in the form of badges
FR20	The user could be able to customize their avatar

Table 4.3: Could have requirements

4.1.2 Non-Functional Requirements

Besides the functional requirements, a set of non-functional requirements were defined. The requirements specified in this section focuses on how the application should behave and perform in terms of usability, performance, reliability, compatibility and maintainability. It was determined early on that the application would be developed as a web application intended to be accessed primarily on computer screens. Therefore, ensuring a responsive design that could seamlessly adapt to

different computer screen sizes was deemed necessary. However, it was not a specific requirement to optimize the design for mobile devices. The non-functional requirements were:

- The application should be compatible and responsive with different web browsers and operating systems to ensure broad accessibility, including Google Chrome and Safari, Windows, and macOS.
- A form for version control should be utilized to keep track of any changes to the codebase and promote collaboration among the developers.
- The application's interface should be intuitive to use, visually appealing, and designed with a focus on the target users.
- The application should offer clear instructions and guidance to users, ensuring that they easily can navigate through the different views of the application and understand the learning material.
- The application should be highly reliable, minimizing downtime and ensuring availability to users.
- The application should be able to handle a number of concurrent users without compromising performance.
- The application should load and respond quickly to user interactions to promote a smooth user experience.
- The application should use a form of local storage to save session data, thereby limiting the number of database queries.

4.2 Design Process

The SLR conducted as part of the preparatory project, presented in Chapter 3, provided valuable insights into existing research on gamification and environmental education, as well as existing solutions in this field. This research served as a foundation for identifying potential development directions. In parallel with defining the requirements, an ideation process was initiated to conceptualize the application's design and interface. Figma[1], a collaborative, browser-based user interface design tool, was utilized for brainstorming ideas and creating both low-fidelity and high-fidelity sketches. The initial sketch focused on visualizing the core functionality of the application, while the high-fidelity sketch incorporated colors, animations, and additional functionality to provide a more specific representation of the desired final product's appearance and interaction. The development of high-fidelity sketches involved an iterative approach, continually refining the design. As the development of the web application commenced, the high-fidelity sketch was further modified to incorporate the design of new features, including the inclusion of a leaderboard, XP, and unlockable levels and items.

[1] https://www.figma.com/

4.2.1 The Science Centre

The Science Center (Norwegian: Vitensenteret) contributed throughout the research by reaching out to participants for the research study, providing dedicated rooms for user testing, and serving as a source of inspiration. The coralQuest application is inspired by one of the movies shown in the planetarium at the Science Center titled *Expedition reef*. This movie is a documentary that showcases the beauty and biodiversity of coral reefs and the scientists taking action to restore them [73]. Figure 4.1 shows a screenshot from the film trailer, and the full preview of the English version can be seen in the video footage provided in the footnote[2]. This movie was selected as an inspiration for the gamified application due to its strong correlation to environmental education. It was compelling for both the authors of this thesis and The Science Center to see if and how the use of a gamified application could elevate the learning experience of the visitors. After deciding on the movie about coral reefs, a brainstorming process began. It was decided early on that while the application should inform and educate the users about environmental issues related to coral reefs and the ocean, the application should have a broad focus on the positive aspects of coral reefs as well in order to avoid feelings of distress and fear related to climate change among the students [24].

Figure 4.1: Screenshot from the *Expedition reef* film trailer.

[2]Full preview: https://www.fddb.org/fulldome-shows/expedition-reef/

4.2.2 Initial Design Sketches

Alongside the brainstorming process, initial sketches were made. They included a simplistic visualization of the application's main functionality and interface. One sketch featured a view for choosing an avatar, and one sketch displayed various quests the user could do to complete the game. These initial sketches can be seen in Figure 4.2.

One of the proposed quests within the application was a quiz designed to test users' knowledge. During the quiz, a pedagogical agent represented as an octopus, would provide feedback to users, explaining why their answers were either correct or incorrect (see Figure 4.3). Another proposed quest involved a virtual scuba diving experience in a digital coral reef, utilizing Google Earth to provide an immersive environment. Within this scuba diving quest, users would have the opportunity to explore, make observations and even share interesting thoughts they made along the way. This quest idea aimed at facilitating subconscious learning [10]. The quiz quest aimed at facilitating learning by making the user recall information obtained from watching the movie prior to using coralQuest.

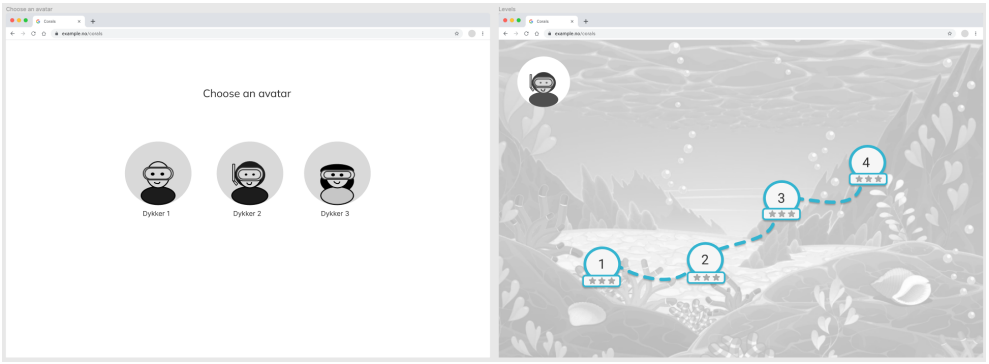


Figure 4.2: Low fidelity design sketch of select avatar and quest-page

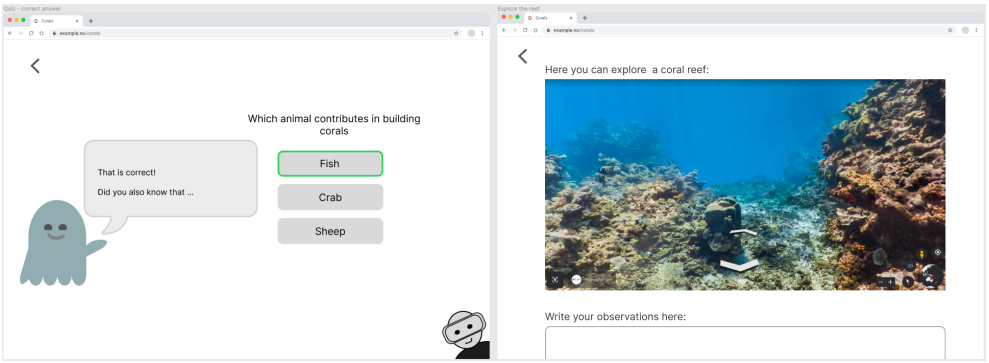


Figure 4.3: Low-fidelity design sketch of the two quests: quiz and scuba diving

4.2.3 High-Fidelity Sketches

Through an iterative design process, a high-fidelity prototype was developed, refining and enhancing the main functionality of the initial prototype. Design adjustments were made while the functionality from the initial prototype was preserved. In addition, the high-fidelity prototype incorporated various new elements, such as colors, illustrations, and new functionality, to enrich the user interface and overall user interaction.

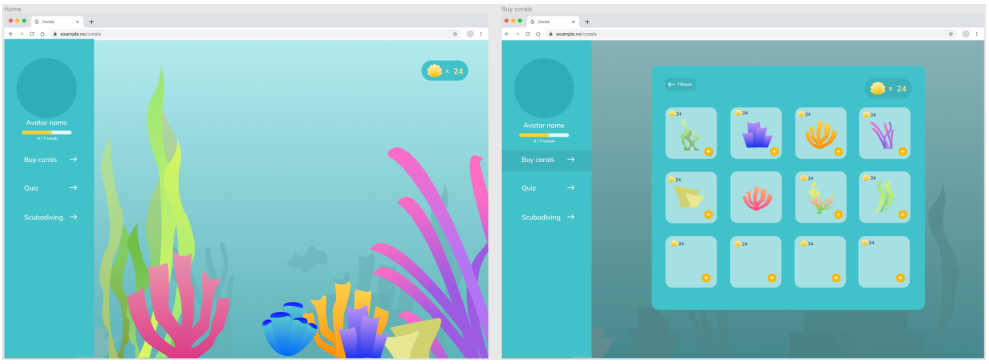


Figure 4.4: High-fidelity design sketch of the home screen with corals and coral-shop

In the high-fidelity sketch, the quests are moved to a navigation menu on the home screen (see Figure 4.4). This version empowers users to choose which quests they want to complete and in which order, granting them more freedom of choice within the game, which is a key element in SDT [39]. In addition, a virtual currency called *Sand dollar*, named after a type of seashell, was introduced.

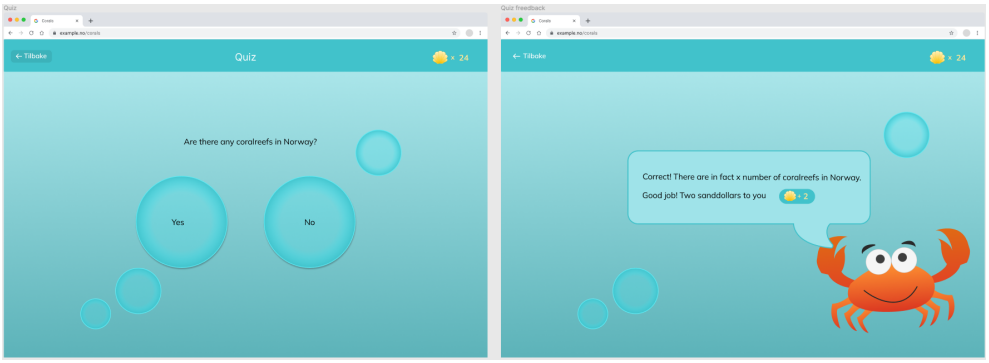


Figure 4.5: High-fidelity design sketch of quiz with the pedagogical agent

The high-fidelity sketch of both the quiz (Figure 4.5) and the scuba diving quest (Figure 4.6) closely resembles the initial sketch, with the addition of vibrant colors. To enhance the immersive experience and align with the storyline of embarking on an actual scuba diving trip, the concept of incorporating a border around the Google Earth view to resemble diving goggles was proposed.

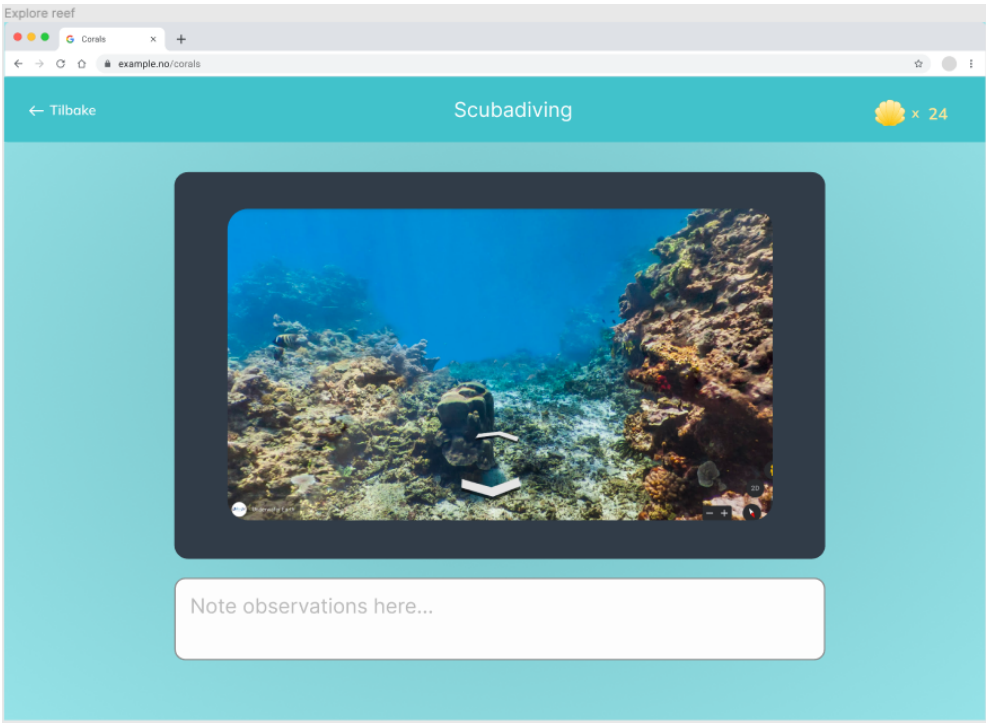


Figure 4.6: High-fidelity design sketch of scuba diving quest

A key consideration during the design process was to incorporate game elements with a clear purpose, avoiding arbitrary additions [14]. The selection and implementation of game elements were informed by previous research and game theory principles. One of these was the Octalysis framework developed by Chou [14]. This framework is widely utilized for designing gamified activities and focuses on the eight core drives of players for effective gamification. It adopts a human-centered approach, concentrating on internal motivations that have been shown to be beneficial in creating a positive and enjoyable gaming experience. The core drives includes aspects of social influence, unpredictability, ownership, and accomplishment, among others [14]. The GameFlow model developed by Sweetser and Wyeth [35] emphasizes enjoyment as the single most important goal of digital games and reports findings on elements that make games enjoyable [35]. By drawing from established theories and frameworks such as these, the game elements were designed to create an enjoyable and engaging player experience.

4.3 Game Elements

The following section will expand on which game elements were implemented in the coralQuest application, their function, and the reasoning behind their implementation described through the lens of the Octalysis framework [14], the GameFlow model [35] and relevant findings from the SLR.

4.3.1 Storytelling

Storytelling in gamification involves integrating a captivating narrative into a gamified application. This concept is exemplified in coralQuest, where users embark on a journey through various coral reefs. The pedagogical agent (described in Section 4.3.3) and the Scuba diving quest act as narrative elements, enhancing the overall storytelling experience. The implementation of storytelling can serve as a way to immerse the players into a game and make them feel like they are a part of the story [35]. This aspect is integral both in the Octalysis framework and GameFlow model [14, 35].

4.3.2 Avatar

In gaming, an avatar refers to a digital representation or character that players control and customize to represent themselves within a virtual world or game environment. Avatars allow players to personalize their gaming experience, expressing their identity and style while interacting with other players and the game world. The avatar in coralQuest is implemented as a scuba diver in three different possible colorways; blue, yellow, and purple. The user is prompted to choose one upon logging in. It is possible to change the avatar whenever the user wants to throughout the game. According to the Octalysis framework, an avatar is a part of the core drive called *Ownership*. This core drive is shown to motivate the users because it can make them feel like they own something, in this case, their own avatar [14].

4.3.3 Pedagogical Agent

Pedagogical agents are interactive characters that assist users in multimedia learning environments, functioning as learning partners or virtual tutors in educational software [74]. In coralQuest, the pedagogical agent is implemented in the form of an orange crab. The Crab provides an initial welcome message to the user, instructions on how the application works, and what the possibilities are. The Crab is also an important part of the two quests Quiz and Scuba Dive (described in Section 4.3.4). The implementation of a pedagogical agent was inspired by findings from the SLR that showed a lack of research on this game element in the context of gamified applications for K-12 students in environmental education. The pedagogical agent also contributes in enhancing the storyline.

4.3.4 Quest

A quest refers to a specific task or mission that players undertake within a game or gamified application. It typically involves a goal to achieve, challenges to overcome, and a sense of progression or accomplishment. It was decided to include two main quests in the coralQuest application; a quiz and a virtual scuba diving trip. The quiz has three difficulty levels. As described in the GameFlow model by

Sweetser and Wyeth [35], challenges in games should match players' skill level, if there is no challenge or if the challenge is too easy, the users will perceive the game as boring; if it is too hard, it becomes discouraging [35]. According to the Octalysis framework, quests are related to the internal drive of *Accomplishment* where a player is making progress, developing skills, and overcoming challenges [14].

4.3.5 XP

XP are a prevalent feature in games, usually obtained by accomplishing tasks like defeating enemies, completing quests, or exploring new areas. This element is related to the core drive *Accomplishment* and is rewarded to the player as they overcome challenges. XP serves as a measure of a player's progress and expertise, determining their level within the game, and is a form of reward related to extrinsic motivation [39].

4.3.6 Progress Bar and Levels

A progress bar is a game element that provides feedback to the player in a graphical format about their current status in the game. The GameFlow model highlights the importance of implementing feedback into gamified applications in a way that ensures players always know their status and score. This ensures that the player can feel a sense of control over how they are progressing in the game, and it can motivate them to continue playing [35]. In coralQuest, the progress bar displays the user's current level and the amount of XP required to level up. There are three levels, each with a different specific XP threshold to progress to the next level. Each level unlocks three new corals, which are further detailed in Section 4.3.8.

4.3.7 Virtual Currency

Virtual currency is a key element of gamification and consists of coins or tokens used to reward players and create an in-game economy. This element is related to the core drive of *Ownership* as expressed in the Octalysis framework [14]. In coralQuest, the virtual currency is implemented in the form of a seashell and named *Sand dollars*. The sand dollars are earned as a reward when answering correctly in the quiz or by completing the scuba diving quest. The sand dollars can be used to buy corals.

4.3.8 Collectibles and Unlockables

Collectibles in gamification tap into the inherent drive to collect and admire, adding an engaging element that provides joy and aesthetic enjoyment to players without necessarily offering strategic advantages [14, 75]. It is also connected to the core drive *Ownership* [14]. It also serves as a reward for when users accomplish tasks and good results [35]. In coralQuest, corals are introduced as collectibles.

Users have the opportunity to purchase corals using earned sand dollars to enrich their coral reef with corals of vibrant colors. The corals are priced differently, requiring users to achieve good results in quests to afford certain ones. Moreover, new corals are unlocked once the user reaches new levels, with three new corals becoming accessible upon leveling up. In addition, new quiz difficulty levels are unlocked as the user successfully completes a quiz, facilitating an increase in challenge alongside players' progressing skills [35]. Unlockable items create unpredictability that contributes to making an engaging game [14].

4.3.9 Leaderboard

A leaderboard is a ranking system that lists players based on their achievements or performance, serving as a measure of their success relative to a specific criterion. In the case of coralQuest, a leaderboard is integrated to rank players according to their amount of XP, fostering a competitive atmosphere and enhancing player engagement. The leaderboard features two tabs: one displaying all players and another exclusively showcasing the active user's class, promoting a sense of community and social interaction among friends playing together, which according to Chou [14] can increase effort and involvement in a game. The GameFlow model also emphasizes the importance of social interaction in games [35]. Based on this theory and positive outcomes related to leaderboard discovered through the SLR, it was decided to implement the game element, despite the potential negative consequences in regards to learning outcome found by Leitão *et al.* [6].

4.4 Development Process

To ensure a controlled and efficient development process, the project was divided into five sprints, each lasting between one to two weeks. At the start of each sprint, issues were created in GitHub[3] based on the functional requirements list, and developers were assigned to specific issues after estimating their size and determining their priority. As developers completed their assigned issues, they created pull requests in GitHub, which were then reviewed by the other developer. This review process helped maintain code quality and ensured that deadlines were met, resulting in a finalized application ready for user testing. To facilitate the smooth deployment of new code and minimize the introduction of bugs in the production environment, GitHub Actions were employed.

[3] https://github.com/

4.5 Application Architecture

The coralQuest web application is built using React[4] with Typescript[5]. The application uses Firebase's Realtime Database[6] to store user data and Firebase authentication for handling user sessions.

Next.js[7] is a React-based web application framework that leverages server-side rendering to optimize page load time. TypeScript, a statically-typed subset of JavaScript, is employed to detect errors more conveniently during the compilation phase. The cloud-based platform Firebase is utilized for secure authentication through the Firebase Authentication SDK, website hosting via Firebase Hosting, and data storage with the Firebase Realtime Database SDK. The Firebase Realtime Database is a NoSQL cloud-hosted database that ensures real-time data synchronization in a JSON format. Firebase was chosen due to its quick and secure implementation.

While the majority of components were created from scratch, a couple of libraries were utilized to expedite development and enhance certain features. Animate.css[8], a CSS library, was employed to assist in implementing animations within the application. This library provides a collection of pre-defined CSS classes that can be applied to elements to create various types of animations, saving development time and effort. Additionally, the Material-UI library [9] was used to create the pop-up window and tab components in coralQuest. Material-UI offers a comprehensive set of pre-designed and customizable React components following the Material Design guidelines.

The chosen application architecture for coralQuest is depicted in Figure 4.7.

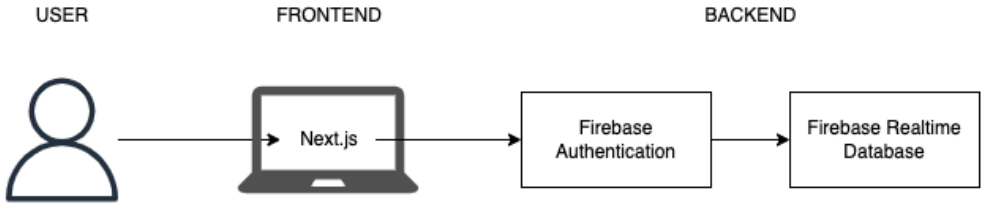


Figure 4.7: Application architecture

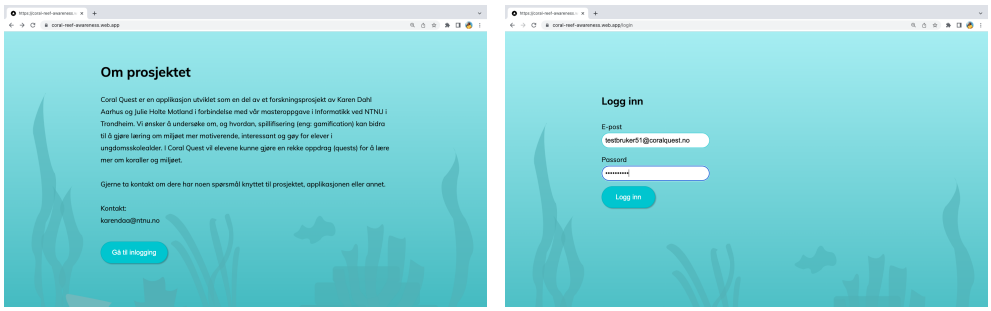
[4]https://react.dev/
[5]https://www.typescriptlang.org/
[6]https://firebase.google.com/
[7]https://nextjs.org/
[8]https://animate.style/
[9]https://mui.com/

4.6 Final Application

The final application has four views that can all be accessed from the navigation menu on the left-hand side, in addition to the *Login* view. These views will be elaborated on in more detail below.

4.6.1 Login

Information about the application and the master thesis project was included on the landing page, which was shared with parents in an information letter to obtain their consent. The landing page provided an overview of the project and the purpose of the application. To proceed, users could click the button at the bottom of the page, which would redirect them to the *Login* view. The views are displayed in Figure 4.8.



(a) Landing page **(b)** Login view

Figure 4.8: Login

4.6.2 Avatar View

After successfully logging in, the users are met with the *Avatar* view (Figure 4.9). In this view, the user can choose between three different avatars and come up with their own avatar name.

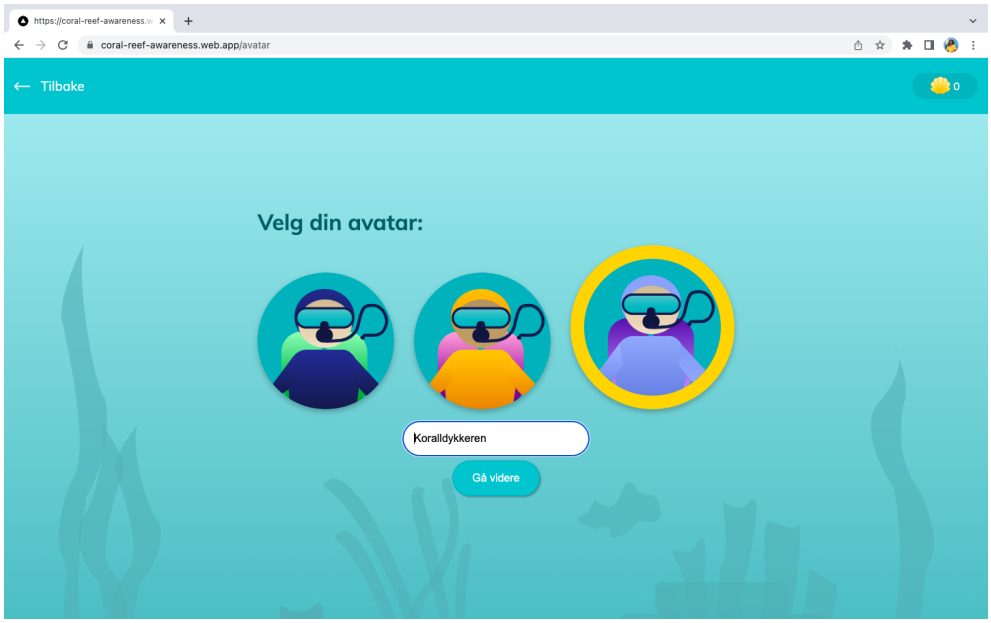


Figure 4.9: Select avatar

4.6.3 Home View

The *Home* view of the application (Figure 4.10) provides the user with an overview of all the activities in the application. Upon initial login, users are greeted by the pedagogical agent, the Crab, who provides a welcome message and encourages the user to explore all the available quests. The view represents the user's personalized coral reef, which can be restored to its vibrant state by earning XP and sand dollars to purchase corals.

The left side of the screen features a navbar that provides links to different views and displays the user's avatar, username, and progress bar. The progress bar displays the user's level visualized within a starfish, their current XP, and the amount of XP needed to reach the next level. coralQuest includes three levels for users to progress through.

Figure 4.11 displays the home screen after the user has reached the third level and bought all possible corals. After specific corals are bought, the coral reef is populated with animated fish, seahorses, and a turtle, which appear as animations swimming through the reef.

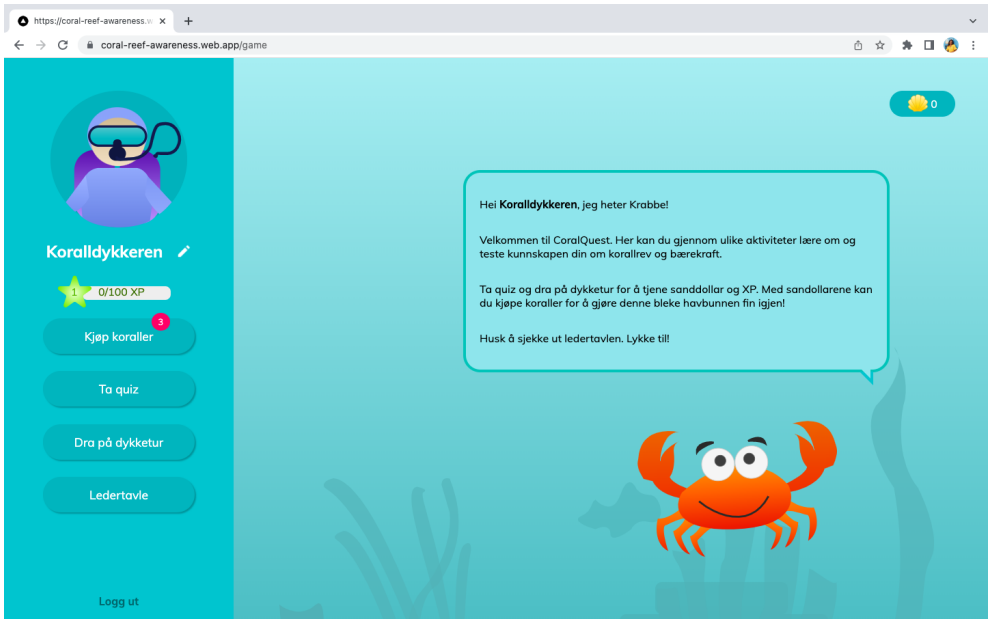


Figure 4.10: Home view after initial login

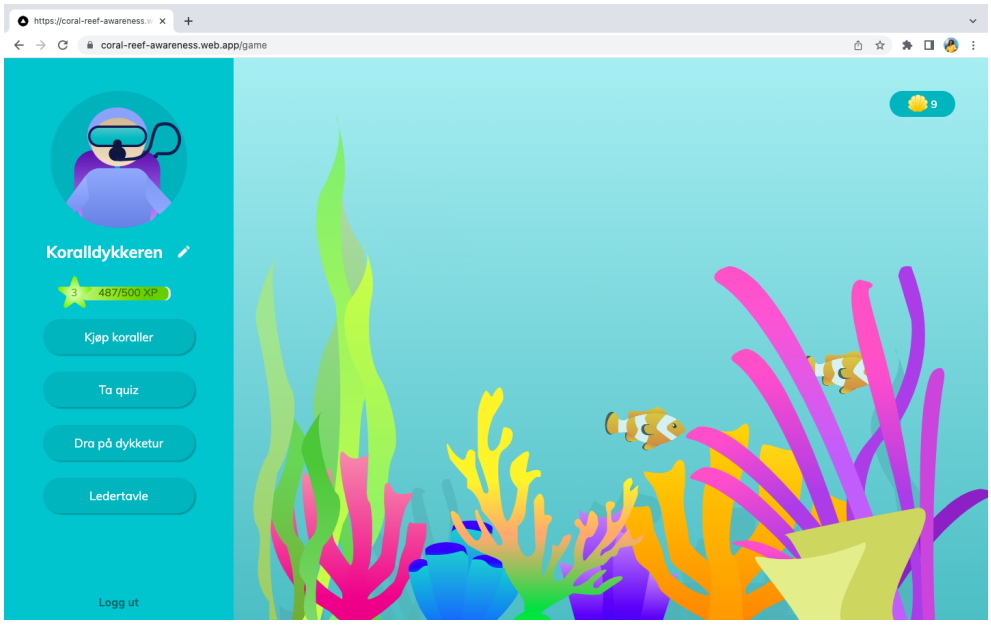
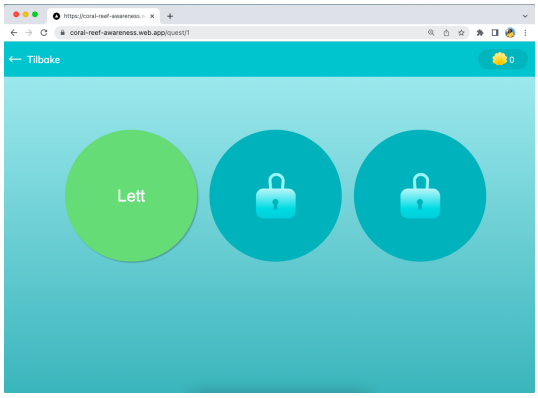


Figure 4.11: Home view with corals and fish

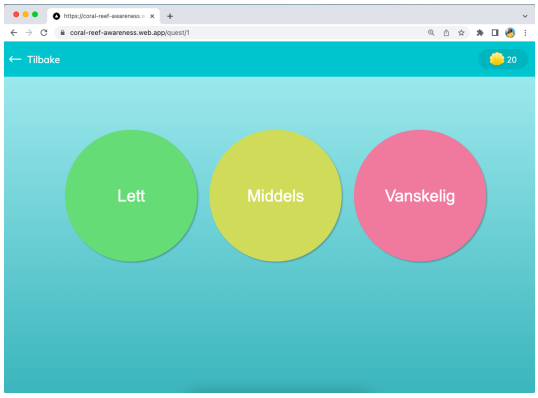
4.6.4 Quiz View

The first quest in the application is the *Quiz*, which is divided into three difficulty levels that are unlocked as they progress through the game. Each quiz consists of five questions that are based on the content of the *Expedition Reef* movie. Users are presented with multiple answer options for each question. When a user selects an answer, it is displayed as green if correct or red if incorrect. In case of an incorrect answer, the correct answer is shown in green as well. After a brief pause, the Crab provides feedback to the user, offering additional information relevant to the question.

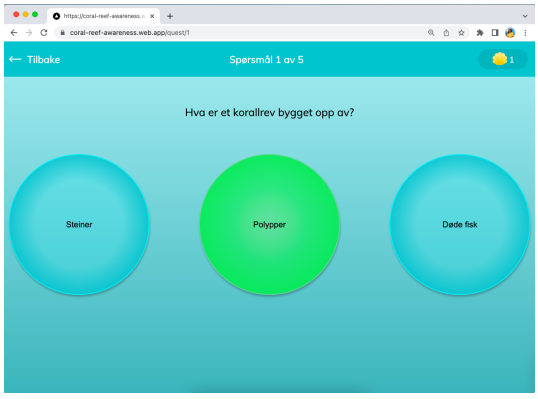
For every correct answer, users earn sand dollars and XP, with the amount increasing based on the difficulty level of the quiz. The users can keep track of their sand dollar (virtual currency) count in the header at the top of the view. Additionally, the header displays the current question number out of the total five questions. Figure 4.12a illustrates the Quiz view that users encounter at first, while Figure 4.12b shows the view when all the quizzes have been unlocked.



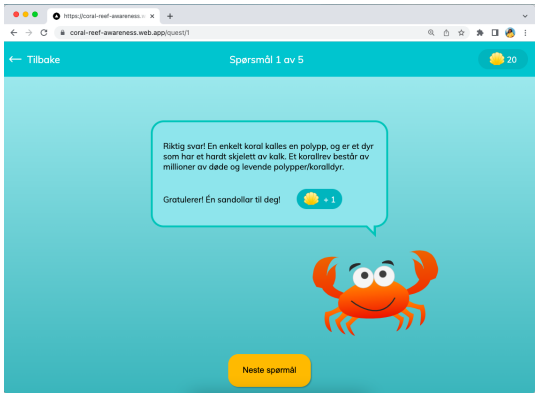
(a) Initial quiz view



(b) All quizzes unlocked



(c) Quiz question

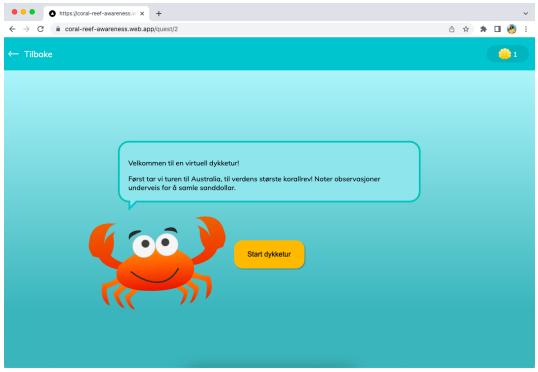


(d) Quiz feedback

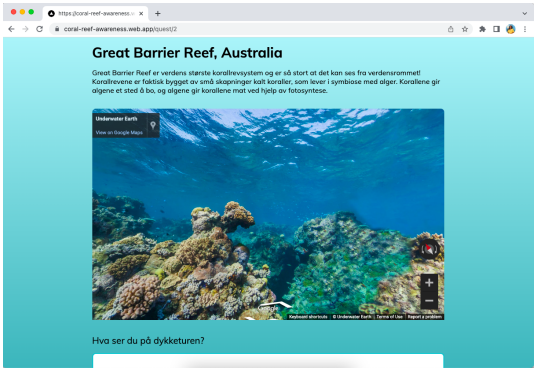
Figure 4.12: Quiz quest

4.6.5 Scuba Dive View

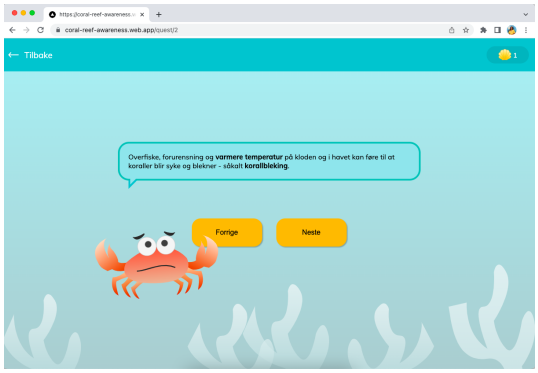
The Scuba Dive quest incorporates a captivating storyline in which users have the opportunity to explore multiple coral reefs using the Google Earth API. The initial idea of creating an impression of diving goggles around the coral reefs was discarded as making the diving view as big as possible was prioritized. At each coral reef site, users receive informative content and are presented with a free-text question where they can input their observations. The Crab provides feedback and additional information to the user between each stop. For example, as seen in Figure 4.13c and Figure 4.13c, the users are educated about and given the chance to visit a bleached coral reef.



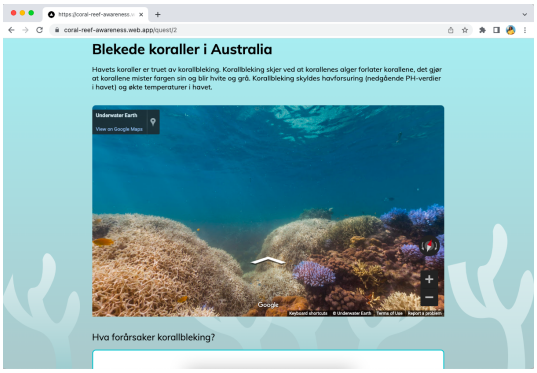
(a) Welcome view of scuba diving quest.



(b) First stop on the scuba diving quest.



(c) One of the scuba diving locations.



(d) Users can explore a bleached coral reef.

Figure 4.13: Scuba diving quest

4.6.6 Coral Shop View

The *Coral shop* view is a pop-up modal accessed from the Home view and can be seen in Figure 4.14 and 4.15. It enables users to purchase corals, which in turn contribute to revitalizing their coral reef by adding vibrant colored corals. As the user progresses through each level, three new corals are unlocked. Each coral has

a unique price and can only be purchased once the user has earned enough sand dollars by successfully completing tasks in the quests.

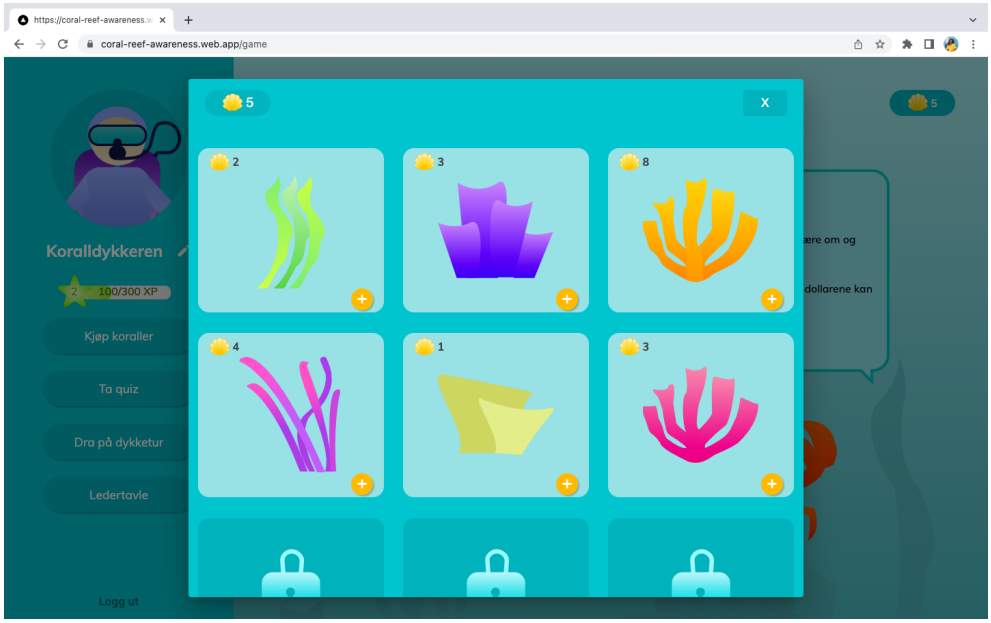


Figure 4.14: The coral shop popup

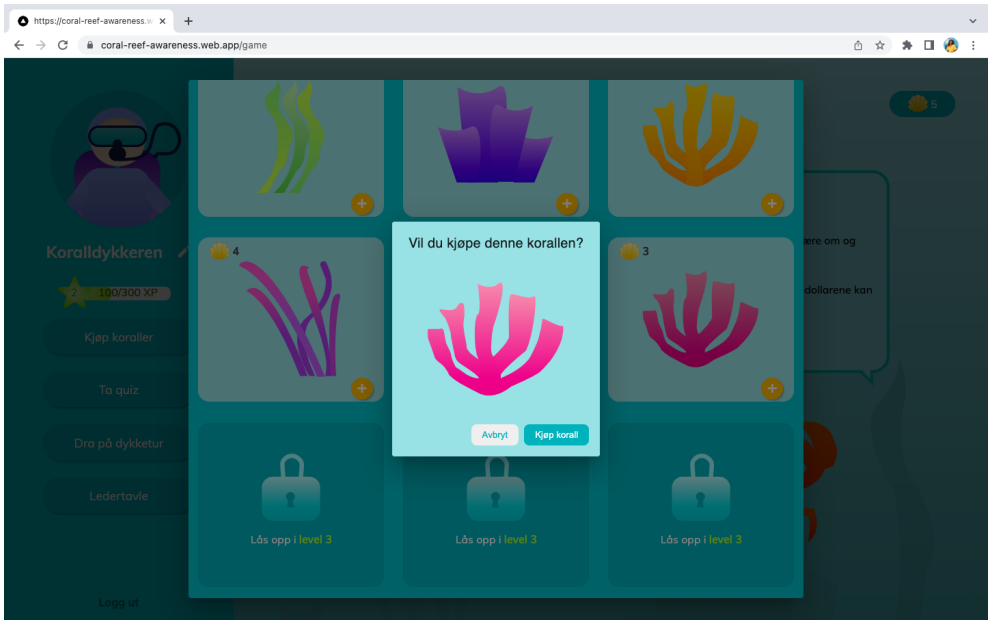


Figure 4.15: Attempting to buy a coral

4.6.7 Leaderboard View

The *Leaderboard* serves as the final view of the application, allowing users to view the top five users with the highest amount of XP (Figure 4.16). Additionally, users can also find their own ranking on the leaderboard. The leaderboard consists of two tabs: one tab displays the all-time rankings of all users who have utilized the app, while the other tab showcases rankings specifically within the user's class or group. Only the top five users will appear on the leaderboard in order to prevent negative feelings among students who have a lower ranking.

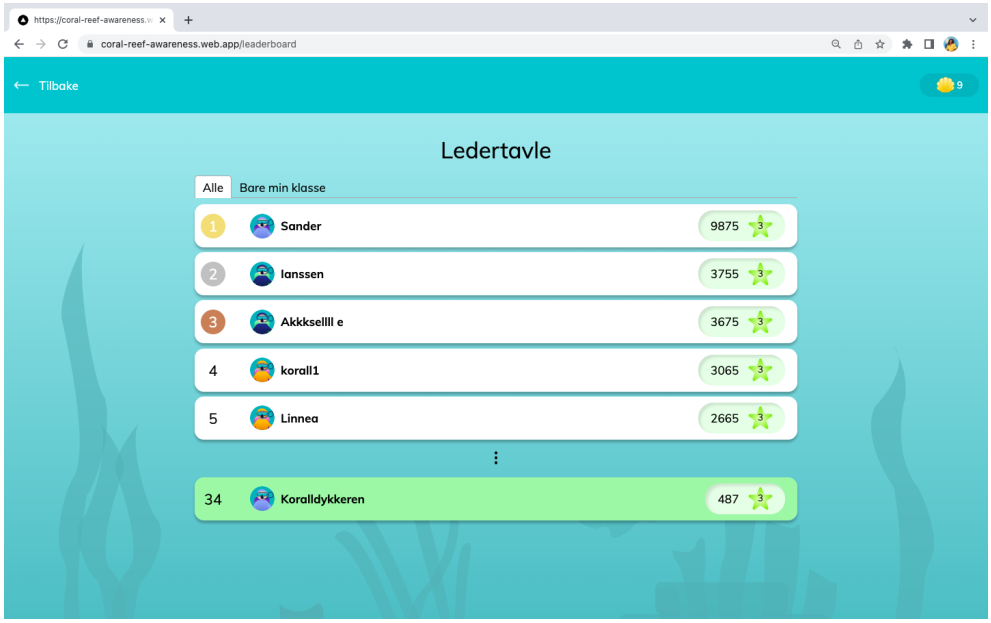


Figure 4.16: Leaderboard

Chapter 5

Method

This chapter describes the research method used for the empirical study conducted as a part of this thesis. First, the research design will be presented before the data collection and variables from the data set are introduced.

5.1 Research Design

RQ1: What effect does the gamified application coralQuest have on K-12 students' learning experience? and RQ2: How does coralQuest affect students' perceptions of environmental education?. To answer the RQ's of this thesis, a within-subjects study was conducted using a mixed-method data collection approach. The data collection was conducted at The Science Centre in Trondheim, providing a suitable environment for gathering data about the participants' interaction with coralQuest. Quantitative data was collected through pre- and post-test questionnaires and game performance data stored in the database. Qualitative data were gathered through observations of the participants as they interacted with the coralQuest application and through semi-structured interviews, in addition to usage data collected through open-ended questions asked during the diving quest in the application. By collecting data from multiple sources, triangulation was established. Triangulation in research refers to the utilization of diverse data sets, methodologies, theories, and/or investigators to address a research question, validate findings, and augment their validity, as articulated by Oates [76]. The present study incorporates both method triangulation and investigator triangulation, as it incorporates multiple data generation methods while being conducted collaboratively by two researchers.

5.2 Participants

The Science Centre in Trondheim provided assistance in recruiting school classes to be a part of the study. Despite facing initial challenges during the recruitment

process, one of the schools that were contacted joined the study, securing 13 students. Furthermore, recognizing that the response received by The Science Centre was not as positive as initially anticipated, the authors undertook additional recruitment efforts. By contacting teachers in the authors' contact network, another group of 28 students was recruited. Ultimately, two groups from separate schools agreed to participate, leading to the involvement of a total of 41 students in the study.

The 41 participants in the study consisted of 24 males (58.5%) and 17 females (41.5%). All the participants were between the ages of 12 and 14 (M=13, SD=.775, min=12, max=14).

5.3 Procedure

Before the testing phase began, a process was initiated with SIKT (Norwegian Agency for Shared Services in Education and Research) to obtain the necessary authorization for collecting sensitive data, i.e., voice recordings, from the participants. Once the approval was granted by SIKT, an information letter and consent form (Appendix C) were subsequently shared with the teachers, who then distributed them to the parents.

The research process was divided into four distinct phases: a pre-test, a user test, a post-test, and interviews. All of these testing phases were conducted in dedicated classrooms at The Science Centre. Prior to commencing the testing, the participants watched the movie titled *Expedition Reef (Norwegian: Korallrevenes verden)* in the Science Center's planetarium. This movie served as a way to introduce the topic of coral reefs to the participants.

5.3.1 Pre-Test

The participants were asked to answer the pre-test questionnaire before testing coralQuest. The questionnaire was integrated into the application, ensuring a seamless user experience. The questionnaire in its entirety is available in Appendix A. The students spent approximately 2-3 minutes answering the pre-test. Upon completion of the pre-test questionnaire, the participants were directed to the home screen of the application. To ensure consistency throughout the testing, each student was assigned a note with a unique number at the beginning of the pre-test, which they were instructed to keep throughout the testing process. The pre-test aimed to collect quantitative data, which will be further discussed in Section 5.5.

5.3.2 User Test

After the participants completed the pre-test, they were automatically directed to the application and were free to play as they pleased. Throughout the entire test-

ing process, participants were encouraged to seek clarification or assistance if they encountered any difficulties or had uncertainties about the tasks. The user testing was conducted in two designated classrooms at The Science Centre, displayed in Figure 5.1, and lasted for approximately 20 minutes. This was in line with the initial plan of letting the participants use coralQuest for a half hour, as this left enough time for completing questionnaires and interviews. This turned out to be a suitable amount of time as the application was a prototype and therefore had limited functionality. Most participants had completed all activities within this time frame.

(a) Oppfinnerkjelleren **(b)** Seddelloftet

Figure 5.1: The dedicated spaces for user testing at the Science Centre

5.3.3 Observations

While the students were using the application, their interaction with the application and with each other was observed by the researchers. The levels of engagement exhibited by the students, as well as their communication and dynamics, were closely observed and taken note of for subsequent analysis and interpretation.

5.3.4 Post-Test

Once the participants had tested the application for approximately 20 minutes, they were encouraged to move on to answer the post-test. The post-test was also integrated into the app, and the students were directed to it by logging out of the

application. The post-test questionnaire can be found in Appendix B. The students spent approximately 4 minutes answering the post-test.

5.3.5 Interviews

The final phase of the procedure involved conducting semi-structured interviews with 12 selected participants. The interviews were useful to gather qualitative data that could provide additional data and valuable insights into the participants' thoughts, emotions, and perspectives. They served as a means to uncover additional information that could not be captured through the questionnaires alone. Consent from parents to audio record the interviews was collected by the teacher beforehand through a consent form. The consent form and corresponding information letter that was sent to the parents can be found in Appendix C. The interviews took place in a designated room adjacent to the classroom where the user testing was conducted, ensuring privacy and minimizing distractions. The audio recordings from the interviews were transcribed. It is noteworthy that all the interviewed students belonged to the 7th grade.

5.4 Data Collection

The primary objective of the data collection was to examine the extent to which the gamified application affected students' learning experience and perception of environmental education. Given that the participants were between 12 and 14 years old, the data collection methods and tools were tailored to suit this age group's needs and preferences. The variables used in the quantitative data analysis, collected from the questionnaires and application database, are presented in Table 5.1 below.

Variable	Pre	Post	Measure	Value	Description
ParticipantID			Nominal		Unique ID for participant
Age			Ratio		Participant's age
Grade			Ratio		Participant's grade
Gender			Nominal	{m, f}	Participant's gender
Username			Nominal		Participant's avatar name
Enjoyment Playing Digital Games	x		Ordinal	[1,5]	Enjoyment in digital games
Frequency Playing Digital Games	x		Ordinal	[1,5]	Frequency playing digital games
Enjoyment Learning Through Games	x		Ordinal	[1,5]	Enjoyment of learning using games
Enjoyment Learning	x		Ordinal	[1,5]	Enjoyment of learning new things
Interest Environmental Education	x	x	Ordinal	[1,5]	Score interest in EE
Importance Environmental Education	x	x	Ordinal	[1,5]	Score importance EE
Perceived Learning Outcome		x	Ordinal	[1,5]	Score perceived learning outcome
Motivation Environmental Education		x	Ordinal	[1,5]	Score motivation in EE
SUS		x	Ordinal	[1,5]	SUS score of coralQuest
Enjoyment coralQuest		x	Ordinal	[1,5]	Enjoyment of using coralQuest
Total sand dollars earned		x	Ratio	>0	Number of sand dollars earned
Sand dollars spent		x	Ratio	[0-39]	Number of sand dollars spent
XP		x	Ratio	>0	Number of XP gained
Corals bought		x	Ratio	[0-9]	Number of corals bought
Achieved level		x	Ratio	[1-3]	Number of achieved levels
Unlocked quizzes		x	Ratio	[1-4]	Number of quizzed unlocked

Table 5.1: Variables in the dataset

The questions were adapted and inspired by relevant theories and previous studies regarding interest [77], motivation [78], attitude [49], system usability and enjoyment [79] [80]. A portion of the post-test questionnaire was pre-defined questions using scales such as the ones assessing System Usability Scale (SUS) and enjoyment. However, to align the questionnaire more closely to the specific objectives of this study, the remaining questions were tailored and customized. While using pre-defined questionnaires and scales could have provided higher validity and reliability, utilizing them would have extended the length of the questionnaire excessively. Considering the participants would be children with low attention spans, it was deemed more practical and efficient to adapt and draw inspiration from relevant theories and previous studies. This approach led to a limited number of questions per theme, ensuring a concise and manageable questionnaire length. To ensure that the questions were easily understandable by the target group, they were formulated in a language suitable for children. This approach aimed to maintain participant engagement while safeguarding response quality [80]. For the questions regarding usability and enjoyment, a modified version of the SUS designed for children by Putnam et al. [79] was used.

The pre-test aimed to measure the students' interest and attitude toward environmental education. The purpose of the pre-test was to gather data that could later be used to measure correlation and any possible changes compared to the post-test. Therefore, all the questions were Likert scale based, except for the questions about age and gender. Both the pre-test and post-test utilized a five-point Likert scale, with 1 representing answers such as "Not at all" or "Completely disagree", 5 representing "Very often" or "Strongly agree", and 3 indicating "Neutral". A five-

point Likert scale was selected as previous research has suggested it to be a best practice when designing questionnaires for children [80].

In the post-test, the participants were presented with some questions similar to those in the pre-test. This allowed evaluation of the relationship between these variables. The post-test questionnaire also included questions about perceived learning outcomes, enjoyment, and usability.

In order to gain insight into the participants' use of the application, usage data was collected in order to see how the different users performed in the game, how many points they earned, and the corals they bought, among other measures, as seen in Table 5.1.

5.4.1 Interviews

The final step of the study was interviewing some of the participants to gather qualitative data for triangulation in order to cross-verify and validate research findings. The participants with obtained consent forms were asked if they would like to participate and informed that the interviews would be recorded. It was prefaced that participating in the interview was voluntary. As a result of the participant's age, it was necessary to pay extra attention to how the interviews were to conducted. An interview guide was prepared in advance for the semi-structured interviews and can be found in Appendix D. Five of the interviewees were female, and seven were male. All interviews were held in Norwegian.

5.5 Data Analysis

This section outlines the process used to analyze the collected data. The primary goal was to identify any significant patterns or trends within the data and evaluate it with the research questions in mind. The results of the data analysis will be presented in Chapter 6.

5.5.1 Quantitative Data

The data extracted from the questionnaires and usage data were analyzed using the tool IBM SPSS Statistics[1].

Calculating SUS score

The SUS is a questionnaire-based framework for evaluating software usability and overall user experience. Each participant answered ten questions that were used to calculate their individual SUS score of the system. This provides insight into the perceived usability and user experience of each individual user. In addition, by summarizing each of the individual scores and finding the mean, it was possible to

[1] https://www.ibm.com/spss

retrieve an overall score for the usability and user experience of using coralQuest. The framework presents a scale of which scores are acceptable and not. In this study, both scores for each participant and the mean of all scores were computed and are discussed to give an overall evaluation of the usability and user experience of coralQuest.

Correlation

Due to the fact that most of the data came from Likert scale questions and were ordinal, a Spearman rank correlation analysis was conducted between the variables in the data set to identify any relationships. As is pointed out by Oates [76], any correlation between 0.3 and 0.7, both positive and negative, is considered a reasonable correlation. The closer this coefficient is to 1, the stronger the correlation.

Independent Samples T-test

In order to compare the responses of certain subgroups within the sample, independent samples t-tests were conducted. Students were divided into groups based on their answers to independent variables derived from the pre-test. Groups were formed based on their pre-existing interest in environmental education and enjoyment of learning new things. Participants who reported high levels of the particular independent variable were assigned to one group, while those with low levels of the same variable were assigned to the other group. Subsequently, differences in means for the dependent variables Perceived Learning Outcome, SUS, Enjoyment coralQuest, Motivation Environmental Education, Interest Environmental Education, and Importance Environmental Education were measured and assessed between the groups. The significant results are reported in Chapter 6.

Paired Sample T-test

A paired sample t-test was conducted in order to understand changes in perceptions of interest and importance of environmental education before and after interacting with the application. The test aimed to determine whether there was a statistically significant difference in the scores.

5.5.2 Regression

A Linear Regression Analysis was utilized in this study to examine the relationship between the independent and dependent variables that were shown to have strong correlations from the Spearman rank correlation analysis. The regression analysis aimed at creating an estimate of how much the independent variables influenced the dependent variables. It also allowed for the determination of whether the independent variables significantly predicted the dependent variable and how well the model fits the data.

5.5.3 Qualitative Data

To identify patterns and meanings in the qualitative data gathered through interviews, a thematic analysis was conducted. The interviews were recorded using Microsoft Teams[2], which provided real-time transcription. The initial step in analyzing the data involved listening to the interviews and refining the transcription by correcting any errors and separating the text into questions and answers.

The thematic analysis was conducted according to the guidelines by Braun and Clarke [81]. Taguette[3], an open-source web-based document tagging tool for qualitative data analysis, was used to assign codes to excerpts with the same meaning and overall focus. The excerpts with codes were then grouped into themes. The process was conducted in an iterative manner, where codes and themes were revisited and adjusted in order to end up with a complete list. The first iteration was conducted separately by the two researchers before they were compared. This first iteration yielded a high Cohen's kappa score, indicating strong inter-rater reliability. The final themes will be elaborated on in a thematic narrative, presented in Chapter 6.

Qualitative usage data gathered from free-text answers in the application was also collected. Word clouds were used to illustrate the most frequently mentioned topics and words among the answers to get a grasp of the students' learning outcomes. Word clouds was used as they have been shown to be more efficient than tables for visualizing large amount of words mentioned and frequencies [82].

[2]https://www.microsoft.com/en-us/microsoft-teams
[3]https://app.taguette.org/

Chapter 6

Results

This chapter will present the results from the data analysis described in Chapter 5. Both quantitative and qualitative data were collected. Descriptive statistics of the data collection and participant demographics, results regarding SUS score, and results from Spearman correlation tests, paired sample t-tests, individual sample t-tests, and regression will be presented. This chapter also presents a thematic analysis of the qualitative data obtained from the interviews. Additionally, observations made during the user testing will be discussed. Finally, word clouds are utilized to visualize the qualitative data from the free-text answers within the application.

6.1 Descriptive Statistics

This section presents the characteristics of the quantitative data collection. These include min, max, mean, and standard deviation values from the pre-test and post-test results. The sample size is the same throughout the study (N=41) and will not be included in the tables. A Shapiro-Wilk test showed a significant departure from normality (W=.809, p=<.001). Figure 6.1 presents the distribution of the participants based on age and gender.

Figure 6.1: Demographics

6.1.1 Pre-Test Descriptives

As shown in Table 6.1, most of the variables contain values across the entire scale and mean values around 3 (neutral). This indicates that the differences between the students' attitudes towards games, learning, and environmental education vary. The Enjoyment Learning variable has the highest min-value in the data set, indicating that the students generally enjoy learning new things.

	Min	**Max**	**Mean**	**Std. Dev**
Enjoyment Playing Digital Games	2	5	3.93	.755
Frequency Playing Digital Games	1	5	3.39	1.137
Enjoyment Learning Through Games	1	5	3.24	1.220
Enjoyment Learning	3	5	3.85	.691
Interest Environmental Education	1	5	3.32	.850
Importance Environmental Education	1	5	4.05	.835

Table 6.1: Pre-test descriptives

6.1.2 Game Performance Data

The game performance data was obtained through usage data from the application's database, such as earned virtual currency and XP, differs from the Likert scales in the questionnaires because they are automatically recorded and can indicate user behavior. The data variables are not ordinal like the questionnaire data but are measured on a ratio. Therefore, the difference between the minimum and

maximum values and the standard deviation will be larger than on the ordinal data. For example, the average XP earned was 1573.41, but as it is clear from the considerable standard deviation of 1597.285, the actual amount of earned XP varies significantly among the participants. This is also the case for the variables related to the virtual currency sand dollars, where some students earned 18 and some as many as 950, and the average at approximately 35. All the participants, except for two, reached level 3, the highest level in the application. As there were only three quizzes, the max-value of the unlocked quizzes variable is a bit misleading. 4 refers to the users who successfully finished the third quiz with three or more correct answers. These variables are shown in Table 6.2.

	Min	**Max**	**Mean**	**Std. Dev**
Experience Points (XP)	245	9875	1573.41	1597.285
Total sand dollars earned	18	950	145.22	157.089
Sand dollars spent	0	39	35.37	8.567
Corals bought	3	9	8.39	1.41
Achieved level	2	3	2.95	0.21
Unlocked quizzes	2	4	3.83	0.44

Table 6.2: Game performance descriptives

6.1.3 Post-Test Descriptives

The same tendency as in Section 6.1.1 can be seen in the post-test values, shown in Table 6.3. Three of the variables, Motivation Environmental Education, Interest Environmental Education, and Enjoyment coralQuest, have observations across the entire scale.

The Importance Environmental Education variable has the highest min-value in the data set, and this variable also has one of the lowest standard deviation values. This indicates that the students agree on a high level of importance when it comes to learning about the environment.

	Min	**Max**	**Mean**	**Std. Dev**
Motivation Environmental Education	1	5	2.89	.952
Interest Environmental Education	1	5	3.22	.866
Importance Environmental Education	3	5	4.10	.800
Perceived Learning Outcome	2	5	3.63	.799
Enjoyment coralQuest	1	5	3.01	1.081

Table 6.3: Post-test descriptives

6.2 Usability - SUS

The SUS was used to measure the usability and overall user experience of coralQuest. The mean SUS score was 66.40 (SD=14.546), indicating a moderate level of usability for the application. The median SUS score of 67.50 was slightly higher than the mean, suggesting that the scores' distribution was roughly symmetrical and evenly distributed.

A SUS score of 68 and higher is considered above average, and below 68 is below average [83]. The SUS scores of coralQuest varied between 45 and 90, showing a wide range across the distribution. Of all the participants, 21 scored 68 or higher on the SUS scale, while 20 scored below 68.

Figure 6.2 shows that a relatively small number of participants (9) had SUS scores that are classified as "Poor". On the other hand, a substantial portion of participants (32) achieved scores classified as "OK" and higher according to the classification criteria [83]. The variance of 211.6 suggests a fair amount of variability in the data, with some participants finding the application highly usable and having a good experience using it and others finding it less so. Overall, these results suggest that the gamified application has moderate usability, with some potential for improvement.

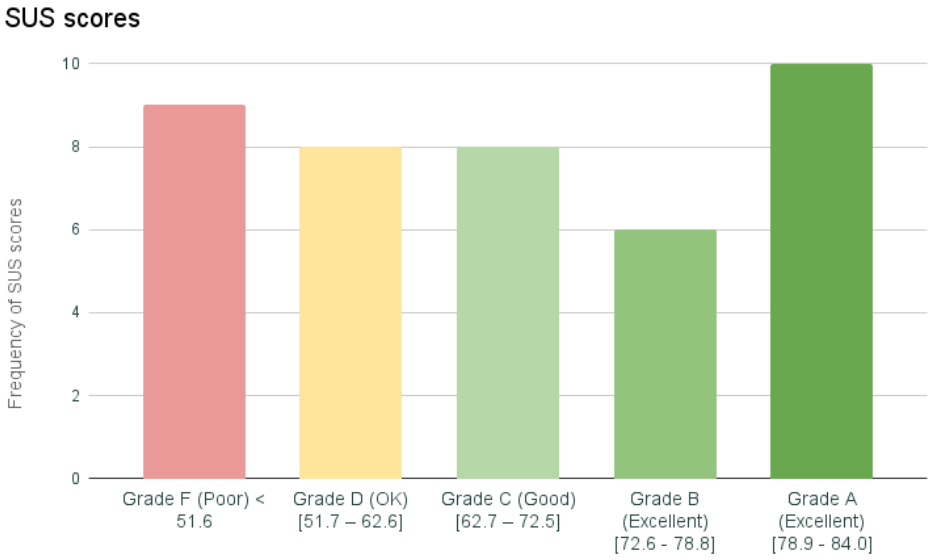


Figure 6.2: Distribution of SUS scores

6.3 Correlations

The following section displays the outcomes of a Spearman Rank Correlation analysis, which was conducted to determine the correlation between the questionnaire data and the game performance data. The results show at which points the correlations were deemed significant.

6.3.1 Pre-Test and Post-Test Correlations

Table 6.4 presents the correlations between the variables in the pre-test and post-test. The variables compared are Frequency Playing Digital Games, Enjoyment Playing Digital Games, Enjoyment Learning Through Games, Enjoyment Learning, Interest Environmental Education and Importance Environmental Education from the pre-test. From the post-test, the variables are Perceived Learning Outcome, Interest Environmental Education, Importance Environmental Education, Motivation Environmental Education, and Enjoyment coralQuest. The two variables Interest Environmental Education and Importance Environmental Education has both pre- and post-conditions; which of the variables being discussed will be prefaced when relevant.

The strongest significant correlations were found between the pre-conditions of Interest Environmental Education and Importance Environmental Education (r= .526, p=<.001) as well as between Motivation Environmental Education and the post-condition for Interest Environmental Education (r=.787, p=<.001).

Several other noteworthy correlations were observed in the study. Firstly, there were significant correlations between both the pre- and post-condition of Interest in Environmental Education and Perceived Learning Outcome (r=.412, p=.008) and (r=.568, p=<.001). Additionally, there was a correlation between Perceived Learning Outcome and Enjoyment coralQuest (r=.415, p=.007), between Perceived Learning Outcome and Motivation Environmental Education (r=.526, p= <.001), between Motivation Environmental Education and Enjoyment coralQuest (r=.467, p=.002), and between Motivation Environmental Education and the post-condition for Importance Environmental Education (r=.430, p=<.001).

	Enjoyment Games	Enjoyment Learning	Enjoyment Learning Through Games	Pre Interest EE	Pre Importance EE	Perceived Learning Outcome	Post Interest EE	Post Importance EE	Post Motivation EE	Enjoyment coralQuest
Enjoyment Games	1									
Enjoyment Learning	-.396* .010	1								
Enjoyment Learning Through Games	-.302 .055	.397* .010	1							
Pre Interest EE	-.110 .495	.378* .015	.321* .040	1						
Pre Importance EE	-.122 .448	.301 .056	.186 .245	**.526**** **<.001**	1					
Perceived Learning Outcome	-.180 .260	.337* .031	.302 .055	**.412**** **.008**	.154 .338	1				
Post Interest EE	-.183 .252	.316* .044	.194 .223	.323* .039	.179 .262	**.568**** **<.001**	1			
Post Importance EE	-.558 .719	.173 .278	.167 .298	.176 .272	**.512**** **<.001**	.175 .274	**.425**** **.006**	1		
Post Motivation EE	-.002 .990	.200 .210	.213 .182	.282 .074	.066 .680	**-.526**** **<.001**	**.787**** **<.001**	**.430**** **.005**	1	
Enjoyment coralQuest	-.033 .837	-.111 .490	.178 .264	.313* .047	-.086 .591	**.415**** **.007**	.392* .011	.021 .899	**.467**** **.002**	1

Table 6.4: Correlation between pre- and post-test variables

6.3.2 Independent Variables with Game Performance and Post-Test

The variables Age, Frequency Playing Digital Games (Experience in Table 6.5), and the calculated SUS score were also compared with the post-test variables and some of the usage data.

	Interest Environmental Education	Importance Environmental Education	Motivation Environmental Education	Perceived Learning Outcome	Enjoyment coralQuest	XP	Sand dollars earned	Sand dollars spent
Age	.175 .275	.252 .112	.053 .740	.262 .098	-.029 .859	.175 .273	.166 .300	-.072 .654
Experience	-.088 .583	.032 .843	.086 .594	-.235 .139	.056 .729	.179 .262	.144 .370	.124 .440
SUS	.115 .475	.340* .030	.161 .315	.178 .266	.078 .626	.324* .039	.348* .026	.203 .204

Table 6.5: Age, Experience and SUS correlations

A slight positive correlation was found between the SUS score and two game performance data variables: Sand dollars earned and XP. This indicates that the students that did well in the application i.e., earned many XP and virtual currency, also found the application to have good usability and an overall positive user

experience. There is also a slight correlation between SUS and the post-condition of Importance Environmental Education, indicating that students who perceived environmental education to be important after using coraQuest also had a better user experience and found the application to have better usability.

6.4 Independent Samples T-Test

To investigate the effects of coralQuest on different subgroups of participants within the sample, independent samples t-tests were conducted. Specifically, groups of participants were formed based on their various degrees of pre-existing interest in learning about the environment and the degree of inherent enjoyment for learning new things. The independent t-test was then used to detect any differences in dependent variables between the groups.

6.4.1 Interest in Environmental Education

An independent samples t-test was conducted to compare the mean scores of different dependent variables between participants with different levels of pre-existing interest in environmental education. The results can be seen in Table 6.6 below. Groups were established after the data was collected. The groups were formed based on participants reported scores on the independent variable Interest Environmental Education that was collected in the pre-test. Group A (Non-Environmentalists) consists of participants that reported that they did not have an interest in environmental education (value of 1-3 on the variable) (26 participants), while participants in Group B (Environmentalists) stated that they were interested in environmental education (value 4-5) (15 participants).

The independent samples t-test revealed significant differences between the two groups on the dependent variables Enjoyment coralQuest($t(39)=2.134$, $p=0.02$), Perceived Learning Outcome ($t(39)=2.351$, $p=.12$), and SUS ($t(39)=1.748$, $p=.044$).

Independent Variable	**Non-Environmentalists (Group A)**	**Environmentalists (Group B)**	**t-value**	**p-value**
Enjoyment coralQuest	Mean = 2.75	Mean = 3.47	2.134	0.020**
	SD = 1.002	SD = 1.093		
Perceived Learning Outcome	Mean = 3.42	Mean = 4.0	2.351	0.012**
	SD = 0.703	SD = 0.845		
SUS	Mean = 63.46	Mean = 71.50	1.748	0.044**
	SD = 12.886	SD = 16.251		

Table 6.6: Independent samples t-test of groups based on interest in environmental education

6.4.2 Enjoyment of Learning

Two groups were formed based on scores on the independent variable Enjoyment Learning, which resulted in two groups: participants that reported enjoying learning new things (value 4-5 on the variable)(28 participants) and participants who did not report to enjoy learning (value 1-3)(13 participants).

As seen in Table 6.7, the test revealed significant differences in means between the groups regarding Perceived Learning Outcome (t(39)=1.836, p=.037) and SUS(t(39)=2.986, p=.002). Other independent variables, such as Motivation Environmental Education and Enjoyment coralQuest, did not show any significant differences in means between the two groups.

Independent Variable	**Non-enjoyers-learning (Group A)**	**Enjoyers-learning (Group B)**	**t-value**	**p-value**
Perceived Learning Outcome	Mean = 3.31	Mean = 3.79	1.836	0.037**
	SD = 0.855	SD = 0.738		
SUS	Mean = 57.31	Mean = 70.63	2.986	0.002**
	SD = 8.688	SD = 14.886		

Table 6.7: Independent samples t-test of groups based on enjoyment in learning

6.5 Paired Sample T-Test

A paired sample t-test was conducted on the whole sample group to compare the variables Interest Environmental Education and Importance Environmental Education before and after using the application. The two-tailed test aimed to determine whether the mean of the two scores in the post-test variable was higher or lower than in the pre-test. The paired sample t-test focused solely on these two variables since they were the only ones consistently tested in both the pre-test and post-test evaluations.

	t	**df**	**Sig. (2-tailed)**	**Mean**	**Std. Dev**
Interest Environmental Education	.644	40	.523	.098	.970
Importance Environmental Education	-.339	40	.736	-.049	.921

Table 6.8: Paired sample t-test

As is displayed in Table 6.8, results show that Importance Environmental Education (M=4.05, SD=.835) increased after using the application (M=4.10, SD=.800). However, this increase was not statistically significant (p=.736). Conversely, the Interest Environmental Education variable (M=3.32, SD=.850) decreased slightly after using the app(M=3.22, SD=.852), yet this difference was also not statistically significant (p=.523) according to the paired sample t-test. These findings indicate that the null hypothesis cannot be rejected, suggesting that there is no

significant difference between the mean values of the pre-test and post-test measurements.

6.6 Regression Analysis

A linear regression analysis was performed to investigate the relationship between the independent variable Interest Environmental Education and the dependent variable Perceived Learning Outcome using coralQuest. This was interesting to investigate as findings from previous research suggests a positive correlation between having an interest in a subject and increased learning outcome [46]. By employing a linear regression analysis, it is possible to investigate whether higher levels of interest in environmental education predict greater learning outcomes from using the gamified application coralQuest. In addition, the regression analysis can estimate how changes in the independent variable can influence the dependent variable.

The two variables (Interest Environmental Education and Perceived Learning Outcome) demonstrated a clear correlation as discussed in Section 6.3; it was therefore interesting to conduct a regression analysis on these variables to see if it was possible to estimate outcomes on the dependent variable. The findings from the linear regression analysis yielded a significant positive association between the two variables (β=.396, t=2.695, p=.010). This implies that for each unit increase in Interest Environmental Education, Perceived Learning Outcome increases by 0.396 units. An R-value of 0.396 and an R-square value of 0.157 indicates that the model accounted for approximately 15.7 percent of the variance in the dependent variable. This implies a small positive correlation found between the independent variable (Interest Environmental Education) and dependent variable (Perceived Learning Outcome) (F(1, 39)=7.265, p=.010), albeit not particularly strong.

6.7 Thematic Analysis of Interview Data

Data gathered from 12 interviews gave qualitative information on the users' perceptions of environmental education, their opinions on the application, and if and how it affected their learning experience. A thematic analysis [81] was conducted to find patterns in order to analyze and interpret the qualitative data. The interview data were grouped into themes, translated into English, and will be presented in this section.

6.7.1 Environmental Education

Environmental education is one of the themes that emerged from the thematic analysis. Several opinions emerged when students were asked about their perception of environmental education. One of the students said:

> "*It is very important to learn about the environment. I think it is actually quite fun*"

There was a trend in the responses; a considerable amount of students perceived environmental education as important and interesting, such as these students:

> "*It is important because you can become smart and know a lot about the climate and things like that*"

> "*Generally, I think it is interesting learning about the environment, how to take care of the environment and stuff like that. It helps to know about it*"

Although many students stressed the importance of environmental education, many also admitted that they found learning about the environment a tad tedious:

> "*I think it is a bit exciting, but for me, it may not be the most enjoyable thing I know*"

> "*I think it is okay. It is a bit boring. But I think it is important to learn about it and know things about it*"

> "*It is exciting, but also a bit boring*"

When asked about their perception of the coralQuest application, one of the students explained that the use of the application could be useful for learning more about the environment:

> "*The app can be good if you want to learn about the environment; you can learn a bit more about the ocean.*"

Many students indicated that they had acquired new knowledge through the use of the coralQuest application. Specifically, their reported learning outcomes included information on coral bleaching as well as expanded knowledge regarding corals and coral reefs:

> "*I have learned about what happens when the coral loses its color*"

> "*I learned, for example, what the world's largest coral reef is*"

> "*I learned that coral reefs grow 0.5 to 2.5 centimeters a year*"

6.7.2 Learning Experience

Although many students stated that environmental education and learning about environmental matters could be tiresome, their perception of the coralQuest application was often shown to be positive. Some of the students stated the following:

> "*I thought coralQuest was fun, and I learned a lot*"

> "*[What I liked the best was] that it was somewhat engaging*"

Many students commented on the educational aspect of the application:

> "*It was a very good app, an educational app. Kind of fun to be challenged with questions*"

> "*[What I liked the best was] maybe that there was a bit of competition in it and that it was educational*"

Additionally, the colors and animations in the application were found to have a positive impact on the learning experience. When questioned about this aspect, students expressed their satisfaction with the choice of colors and animations, describing them as "*pretty*" or that the animations were "*cool*". One student said:

> "*The colors and animations create a vivid image which makes me want to continue playing the game*"

Several students expressed that they would like to play the game again, and most said that they would like to play the game in a school setting:

> "*I could play the game again at school or somewhere similar, but maybe not during my spare time*"

However, a few reported that they would like to play coralQuest at home.

> "*I would like to play the game again at home to show what we did at school and what we learned*"

> "*I think I would like to play the game when I have time off from school, maybe at home*"

Nevertheless, some participants mentioned that they were not inclined to play again. This lack of interest was often attributed to a perceived lack of engaging activities within the application, which will be discussed in more detail in Section 6.7.4. Additionally, some participants expressed that coralQuest failed to capture and sustain their interest, stating they would like to spend their time on other things.

> "*I would not want to play the game again because it is not what I enjoy spending my time doing*"

6.7.3 Gamification Elements

When asking the participants what aspects they enjoyed most when using the application, the scuba diving quest and the competition aspect were mentioned the most. One of the students said:

> "*I thought the quiz was fun. But the most fun was the diving and stuff because you could still move forward even if you answered correctly or not*"

The leaderboard created a lot of engagement among the students, with many considering it their favorite app feature. For many students, the competition created by the leaderboard was the main reason they enjoyed using the app. Almost all the students mentioned they were mainly focused on the leaderboard that displayed only their classmates over the one showing all users.

> "*The best thing about the application was the competition*"

And another added:

> "*It gave a bit of a competitive spirit, and it was cool to be able to see what others were doing.*"

Many students mentioned the point system and the possibility of earning sand dollars as motivating factors to complete more quizzes to earn more sand dollars to purchase corals in the game store.

> "*I liked watching the corals, and that I was able to buy them*"

When another student was asked what motivated them to answer correctly in the quiz, they said:

> "*Yes, I wanted more of those corals*"

The students also found the difficulty levels in the quiz quest enjoyable, as they could adapt to the quiz's difficulty. One student even had a favorite quiz level and mentioned:

> "*I liked the intermediate one the best*"

The students were also asked what they thought about the crab, which acted as the pedagogical agent in the application, and the answers varied greatly. Some found it helpful, some found the crab cute and amusing, while others found it annoying and skipped it altogether to reach their goal of earning sand dollars and XP faster. When asked if they spent any time reading the feedback from the Crab, one student stated:

> "*No, not a lot, I just skipped it*"

When asked a follow-up question about why, the student added:

> "*I was just trying to collect points*"

While some students claimed that they did not need to read the Crab's messages as they already knew what to do, most said they found the Crab's feedback useful and educational:

> "*It was cool. I read what it said because I was not quite sure what to do in the beginning, and it helped me figure out what was possible in the application*"

6.7.4 Suggested Improvements

One of the interview questions was whether the children had any ideas on what could have made the application better. One student suggested:

> "*Maybe adding something more to learn*"

Almost all the students expressed a desire for more quests, quizzes, and activities to engage in within the application. They reported that they quickly completed the existing quests and would have enjoyed having more things to do. When asked if they would have liked to continue playing, one student mentioned:

> "*Yes, if there were more quizzed and questions and stuff*"

Another student said:

> "*Probably not because when you have gone through all of it, maybe it gets a bit boring when you do it a few more times*"

When the same student was asked a follow-up question about whether they would want to continue playing if there were more things to do in the app, the answer was yes.

6.8 Observations

The participants had the freedom to utilize the application for an unrestricted period of time. However, it was observed that the majority of the participants felt done interacting with the application within a span of approximately 20 minutes.

From observations during the testing phase, some students mentioned they wanted the opportunity to customize their avatars and buy additional accessories. One student also had a suggestion for a new feature:

> "*You should include an upgrade feature where you can upgrade the corals by building them bigger. I have a lot of money but cannot do anything or buy anything*"

Another observation made was the question of what purpose coral served in the app. This feedback could suggest the need for more straightforward instructions or explanations of game mechanics in the app.

Other observations made were conversations between the participants. Some participants expressed excitement upon answering correctly in the quiz and thereby shared their success with their peers. Others became competitive and tried to achieve higher scores than their peers. One participant that initially expressed boredom from using the application became more engaged once the leaderboard was discovered. These findings suggest that the application has a social element and fostered positive interactions between the participants.

6.9 Qualitative Usage Data

In this section, qualitative data obtained through the participants' responses in free text answers within the coralQuest application will be presented. Specifically, the participants' responses to questions related to coral reefs in the virtual scuba diving quest. This information gives an indication of the students' learning outcomes and what they found interesting. The responses have been translated and will be visualized using word clouds to provide a concise representation of the most frequently mentioned words.

Figure 6.3 presents a summary of participants' responses to the question "*What causes coral bleaching?*" The word cloud visualization highlights the most frequently mentioned factors. The predominant responses revolved around global warming, specifically emphasizing increased ocean temperatures, ocean acidification, and climate change. Some participants also mentioned additional factors, including pollution, overfishing, and the expulsion of algae by corals.

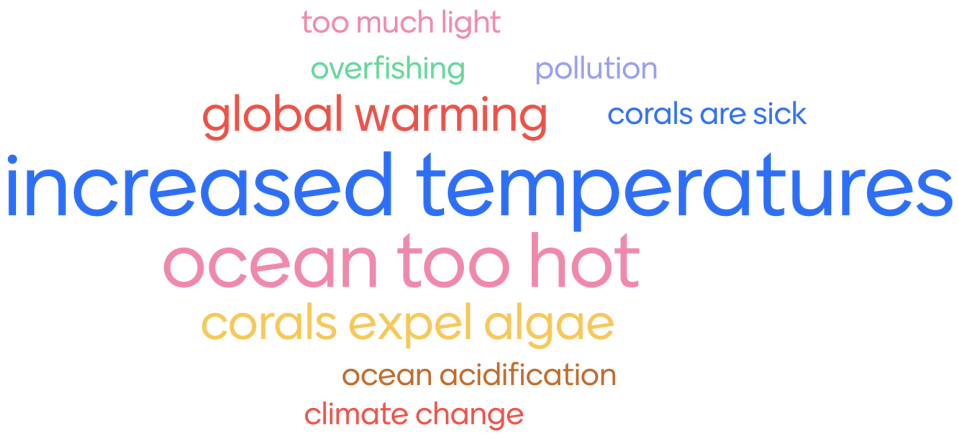


Figure 6.3: Responses to causes of coral bleaching

After receiving a brief introduction to coral farms, participants were asked the question, "*Why are coral farms useful?*" The responses are visualized in Figure 6.4. The majority of participants acknowledged that coral farms serve the purpose of cultivating and restoring corals, especially those that are sick or damaged. Additionally, several students emphasized the significance of coral reefs for human livelihoods. One noteworthy response highlighted the role of coral farms in preventing the extinction of ocean species.

Figure 6.4: Responses to benefits of coral farms

In response to the final question of the virtual diving trip, "*What have you discovered or learned on this virtual scuba diving trip?*" students reported to have observed lots of corals and fish. In terms of learning outcomes, many participants mentioned gaining knowledge about the existence of coral farms. Additionally, several students highlighted their understanding of coral bleaching and its causes. The summarized responses to this question are presented in Figure 6.5, providing a visual overview of the key themes expressed by the participants.

Figure 6.5: Responses to reported learning and discoveries

Chapter 7

Discussion

This study has investigated how a gamified web application can affect the learning experience of K-12 students in environmental education. The relevant findings from Chapter 6 will be discussed in order to answer the RQ's.

7.1 Learning Experience

The purpose of this section is to interpret the findings and results and use them to examine how the learning experience is affected by using the gamified application coralQuest. As mentioned in Chapter 2, learning experience encompasses the experience in which learning takes place. Beyond just the acquisition of knowledge, it is interesting to look at factors such as engagement, enjoyment, and motivation. This information will be used to answer the first research question of this thesis "*What effect does the gamified application coralQuest have on K-12 students' learning experience?*".

7.1.1 Usability and User Experience

The SUS scores serve as an indicator of the overall user experience and usability of the coralQuest application. The results of the SUS scores exhibited diverse outcomes, indicating that the gamified application had both positive and negative aspects concerning usability and user experience. The overall SUS scores indicated a moderate level of usability, suggesting that there is room for improvement. Valuable feedback provided by the participants shed light on specific issues that need to be addressed in order to enhance the usability of coralQuest and improve the overall user experience. This feedback primarily revolved around the desire for additional interactive elements within the application, such as more quizzes and the inclusion of a feature to upgrade the purchased corals and avatar. However, it is important to note that the majority of students reported an acceptable or higher SUS score, and all interviewees expressed finding the app easy to use. Im-

plying that the gamified application was generally usable among the participants. Adding the suggested improvements could contribute to enhancing the overall user experience.

7.1.2 Game Elements

This section aims to provide a summary of the findings related to some of the game elements implemented in coralQuest and their alignment with the existing literature.

XP and Leaderboard

Implementations of leaderboards in gamified applications have, in previous research, yielded contradicting results Leitão *et al.* [6]. During the user testing phase of coralQuest, it was observed that certain students became highly competitive in their efforts to secure the top position on the leaderboard, accumulate the highest number of points, and outperform their peers. Consequently, these students adopted a strategy of swiftly progressing through the quizzes by relying on memorizing the correct sequence of answers rather than comprehensively reading and understanding the questions. This approach may have had a negative impact on their learning outcomes. This finding aligns with the research conducted by Leitão *et al.* [6], who reported that the incorporation of leaderboards can foster competitiveness, which in turn can have negative effects on students' learning outcomes.

Still, the implementation of a leaderboard in this study resulted in positive effects in regard to student engagement. Qualitative data gathered from observations and interviews suggested that students exhibited increased motivation to continue playing coralQuest and achieve higher scores upon discovering the existence of the leaderboard. This finding aligns with research conducted by Andrade *et al.* [57] and Leitão *et al.* [6], which emphasized the influential role of leaderboards in fostering student engagement.

In the interviews, many students mentioned the leaderboard as their favorite element in the application. The students reported that they enjoyed looking at who had the highest rank on the leaderboard and that this motivated them to try to beat their opponents. This finding aligns with previous studies that have found leaderboards to be effective in enhancing student motivation, enjoyment, and engagement [6, 38, 57, 69]. A majority of students indicated a preference for tracking the leaderboard specific to their own class rather than the one encompassing all users who had ever played coralQuest. This preference aligns with SDT and the concept of relatedness, as the class-specific leaderboard provides students with a sense of community and connection with their peers while playing [39]. This social aspect is also acknowledged in the Octalysis framework, which highlights that social influence and a sense of relatedness can enhance individual performance beyond what would be achieved in the absence of social interaction [14]. For instance, the discovery of a friend achieving a higher score can motivate an

individual to improve their own performance [14], which corresponds with the findings regarding coralQuest and leaderboards. An example of this was observed during the user testing. One student initially found coralQuest to be tedious, but upon encountering the leaderboard and realizing that the classmates had higher scores, the student became engaged and continued using coralQuest with the aim of achieving a better score. This indicates that the presence of social influence served as a motivating factor, leading the student to persist with the application, which could potentially yield improved learning outcomes.

Pedagogical Agent

Among the studies included in the SLR, only three mentioned the use of a pedagogical agent. While the study conducted by Garneli *et al.* [68] did not report any specific findings related to this game element, Priyadarshini *et al.* [55] found the pedagogical agent to be a useful game element. Furthermore, the research conducted by Ying *et al.* [67] demonstrated that the incorporation of a pedagogical agent positively influenced students' learning outcomes.

In this thesis, user tests of coralQuest revealed that many students had positive perceptions of the pedagogical agent. It was described as amusing and helpful for understanding how to navigate the application. This aligns with similar observations made in the studies conducted by Ying *et al.* [67] and Priyadarshini *et al.* [55], suggesting that the presence of a pedagogical agent can be advantageous for certain students, as it positively contributes to their learning experience by providing feedback, enhancing enjoyment, and facilitating learning.

However, a subset of students expressed that they did not always read the information presented by the pedagogical agent in coralQuest. This observation suggests that the pedagogical agent might have provided an excessive amount of information or appeared too frequently throughout the application. Some students even found the pedagogical agent to be bothersome and preferred to continue playing the game instead of reading its feedback. This indicates that the presence of the pedagogical agent disrupted the flow of the game for certain students. It is essential to minimize such disruptions as maintaining a state of flow is highly advantageous [35]. Prior research has demonstrated that achieving a state of flow can enhance motivation, engagement, and overall learning outcomes, among other benefits [14, 35]. Therefore, ensuring a seamless integration of the pedagogical agent within the game environment without disrupting flow is crucial. Further research in this area is warranted to explore and address these concerns.

Quests

An integral aspect of SDT is the emphasis on autonomy and freedom of choice. In the context of gamification, this principle is incorporated into coralQuest by offering players a choice of various activities to engage in and corals to add to their reef. By providing users with the ability to select what they want to do within the

application and granting them a sense of freedom of choice, their motivation can be enhanced [39]. About half of the participants reported enjoying the scuba diving quest the most, while the other half reported enjoying the quizzes. By granting them freedom of choice, the application facilitated for students to choose to do the activities they enjoyed the most and spend less time on things they did not like as much.

During interviews, when students were asked about their willingness to continue using the application, nearly all respondents expressed that they would be more inclined to do so if there were additional activities available. As the coralQuest application was developed as a prototype, it only featured two quests, which proved to be too limited. In a future iteration of the application, the existing quests could be extended by adding more tasks, and new types of quests could be implemented.

During the interviews, the scuba diving quest was often mentioned as one of the most enjoyable things to do in the application. This quest facilitated exploration and subconscious learning, which according to Mee *et al.* [10], is a gamified learning activity often preferred by students in primary education. Based on this finding, it can be interesting to further investigate ways to implement subconscious learning into gamified applications.

7.1.3 Learning Experience in Different Student Types

The findings of this study revealed that a specific subgroup of participants had a more favorable learning experience compared to others. This suggests that the coralQuest application did not effectively cater to the diverse learning needs and preferences of all students. While the majority of students expressed positive views about the application, quantitative data indicated that certain individuals had negative perceptions of the overall experience. The variations in experiences among participants will be further examined and discussed in detail in this section.

Among the participants of this study, certain findings emerged regarding individual factors. It was observed that students who expressed pre-existing enjoyment in the process of learning new things exhibited higher perceived learning outcomes and obtained higher SUS scores compared to those who expressed a lack of enjoyment from learning. This indicates that students with an inherent enjoyment of learning new things benefited more from the gamified application. This finding aligns with previous research, which suggests that students who experience enjoyment in an educational setting tend to invest more effort in comprehending new information: They also have higher levels of memory retention and cognitive processing and overall have a more positive learning experience compared to students without this experience of enjoyment in the subject [32, 33].

Similar findings were found regarding students with a pre-existing interest in environmental education compared to students without this interest. These students exhibited higher levels of enjoyment in using coralQuest, higher perceived learn-

ing outcomes, and higher SUS scores than their peers that did not have an initial interest in environmental education. The regression analysis showed that a pre-existing interest in environmental education estimates an increase in perceived learning outcomes. The findings are in line with research conducted by Silvia [46] suggesting that interested students often achieve higher academic results than uninterested students [45, 46]. This reinforces the importance of considering students' individual interests and preferences when designing gamified software for education.

Another noteworthy relationship was found between students that enjoyed playing coralQuest and their perceived learning outcomes. Students who reported enjoying engaging with coralQuest also reported that they had learned more than students that did not. This indicates that students that obtained greater perceived learning outcomes enjoyed the coralQuest application more than those with low learning outcomes. This finding is consistent with the ones of Hagenauer and Hascher [32], which suggests that students with greater learning achievements are more likely to experience enjoyment, and students with low learning outcomes often do not experience enjoyment with the application. As a result, there is a circular dependency between enjoyment and learning outcomes in this context, meaning that these two variables mutually influence each other [32].

7.2 Perceptions of Environmental Education

How does coralQuest affect students' perceptions of environmental education? One of the most important aspects of this study was to investigate K-12 students' perception of environmental education and to see what effect the gamified application had on these perceptions.

The data analysis results indicated that a majority of students considered environmental education to be important. This aligns with the qualitative data obtained from interviews providing a form of triangulation and reinforcing the consensus among students about the significance of environmental education. However, it is important to note that despite acknowledging its importance, a significant number of students also expressed feelings of boredom or disinterest in the subject. This emphasizes the difficulty of engaging students in environmental education. It underscores the requirement for innovative approaches, such as gamified software, to boost their motivation and foster greater interest in the topic.

When comparing the pre-test and post-test data, a slight increase in the perceived importance of environmental education was observed, although it was not statistically significant. This suggests that the coralQuest application may have influenced the students' perceptions of the importance of environmental education to some extent. This finding is interesting as it indicates a slight shift in the participants' attitudes toward environmental education. Previous research has shown that attitudes can be predictive of behavior [51] and another study has suggested

that positive attitudes towards the environment can eventually lead to an increase in environmentally friendly behavior [52]. Hence, it is crucial to find ways to create or increase environmentally friendly attitudes. One effective approach, as suggested by Bradley *et al.* [50], is to increase knowledge about the environment. Their research demonstrated a correlation between environmental knowledge and attitudes towards the environment, revealing that participants with higher levels of knowledge exhibited more positive attitudes compared to those with lower levels of knowledge [50]. This finding corresponds with the findings of the current study, where a significant correlation was found between perceived learning outcomes from using coralQuest and the importance of environmental education. This may indicate that students with higher levels of perceived learning outcomes have more environmentally friendly attitudes in terms of perceiving environmental education as important. However, this cannot be effectively concluded based on this study.

The assessment of learning outcomes revealed that students acquired new knowledge about coral reefs, environmental issues, and coral reef conservation. Asking students what they had learned not only provided insight into their learning outcomes but could also offer indications of their areas of interest [46]. For instance, some students mentioned specific details such as the annual growth rate of corals, coral bleaching, and the name of the world's largest coral reef. Several indicators suggest that the coralQuest application played a role in enhancing students' knowledge about coral reefs and the global issues that pose threats to them. This increased knowledge among students is highly beneficial as it has the potential to cultivate positive attitudes toward the ocean and the environment [50]. However, it is important to further research the potential long-term effects of such gamified applications on attitudes and environmental behavior.

Significant relationships were identified between the students' motivation to learn about environmental education and their perceived learning outcome, perceived interest, and perceived importance of environmental education after using coralQuest. However, this only identifies a connection between the variables and not causality. The data analysis did not reveal any statistically significant findings indicating that coralQuest impacted the students' motivation to learn about the environment. This is consistent with findings from a study conducted by Andrade *et al.* [57], which also reported no significant differences in motivation. However, it is worth noting that these results contradict the outcomes of previous research conducted by Leitão *et al.* [6], Ricoy and Sánchez-Martínez [62] and Wommer *et al.* [34] where gamified applications were found to have positive effects on participants' motivation to learn about and care for the environment.

7.3 Limitations

It is important to recognize that several limitations might have affected the quality of the results. It is worth noting that this is the first research project conducted by

the authors, and therefore, their inexperience can have affected the data collection and research design negatively. Working with children also poses challenges regarding their credibility when answering questionnaires [80]. Irritation and impatience were observed in some of the students while the questionnaires were answered, indicating that some may have been answered as quickly as possible rather than truthfully.

To enhance the reliability and validity of the results in this thesis, it would have been beneficial to formulate the questionnaires in a manner that ensured greater validity. The use of more than one response for the same construct greatly increases the reliability of the scores [49]. Furthermore, including more questions that measured the same variables both before and after user testing would have improved the analysis.

Another potential limitation of the study is that the interviewees may have provided answers based on what they believed the interviewer wanted to hear rather than their genuine thoughts. This could be the case as the data gathered from interviews generally were more positive to the application than the quantitative data gathered from the questionnaires. Despite being informed beforehand that their honest opinion was sought after and that the application was the sole focus of the test, it cannot be confirmed with certainty that they responded truthfully.

A final limitation of this study is the limited sample size of 41 participants. A larger sample size would have been beneficial for the quantitative data analysis and made it possible to draw more solid conclusions. While many of the findings of this thesis are interesting and add to the body of work that is K-12 gamified education and environmental education, few of the findings were significant.

Chapter 8

Conclusion

This master thesis has investigated the impact of the gamified web application coralQuest on the learning experience and perceptions of environmental education for K-12 students. This was done through an empirical mixed-method study.

The study investigated the influence of game elements incorporated in coralQuest. The presence of a leaderboard positively affected student engagement, motivation, and competitiveness. However, it was noted that some students adopted a strategy of memorizing answers to progress quickly through quizzes, potentially compromising their learning outcomes. While the leaderboard was widely favored by students and served as a powerful motivator for score improvement, it is crucial to strike a balance between competition and knowledge acquisition to ensure the overall effectiveness of the gamified learning experience. Additionally, the incorporation of a pedagogical agent was found to have a positive impact on student enjoyment, facilitating learning and feedback. However, some students perceived the pedagogical agent as disruptive and would prefer uninterrupted gameplay. Consequently, integrating the pedagogical agent seamlessly within the game environment becomes crucial for maintaining a state of flow.

Traditional environmental education was perceived as important but tiresome by students. The gamified application effectively enhanced their learning experience and perceived learning outcomes, suggesting its potential to improve traditional environmental education. While there was a slight increase in the perceived importance of environmental education, it was not statistically significant. Notably, students with pre-existing interest and enjoyment in environmental education benefited more from coralQuest than those without. However, the application struggled to spark interest in initially uninterested students.

The thesis has contributed to a deeper understanding of how children perceive and interact with gamified software in the context of environmental education. The findings emphasize the need for continuous research and improvement to design gamified learning applications that cater to diverse student needs and ef-

fectively engage them in environmental education. By considering these factors and leveraging the potential of gamification, applications like coralQuest have the potential to enhance the learning experience, foster positive attitudes toward environmental education, and contribute to the holistic development of gamified education within the domain of environmental education of K-12 students.

8.1 Future Work

The findings of this study have revealed potential new approaches and ideas for improving both the application coralQuest and the research design.

Based on student feedback from the interviews, it is recommended to incorporate additional quests in the application due to the quick completion of the existing ones. To address the issue of participants memorizing the quiz, introducing a randomized order of the quiz questions could potentially improve learning outcomes. Future studies should explore different approaches to seamlessly integrate a pedagogical agent into the game without disrupting its overall flow. Continued development of the application could involve implementing game elements like badges or avatar personalization, which may yield new interesting findings. Additionally, examining the effectiveness of individual game elements in isolation can provide valuable insights into their impact on the learning experience.

To gain a deeper understanding of how users utilize the application, integrating tools such as Google Analytics or other log data collection mechanisms can be beneficial. These tools can provide useful information on engagement time, page views, and clicks, enabling further analysis of user interaction with the application.

To enhance future similar studies, it is recommended to consider incorporating a larger sample size and implementing a more controlled setting for answering questionnaires. By doing so, researchers can gather more comprehensive data and enhance the reliability of their findings. Due to the short time frame and limited sample size of this study, drawing definitive conclusions regarding the actual effects of the application on the learning experience and perceptions of environmental education becomes challenging. To obtain a satisfactory amount of data and enable conclusive findings, a longer and more exhaustive study would be required.

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Appendix A

Pre-Test Questionnaire

Pre-test coralQuest

Obligatoriske felter er merket med stjerne *

Hva er tallet du har fått utdelt? *

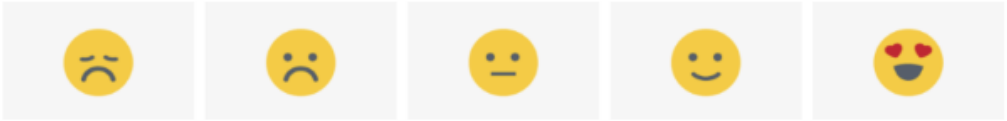
Hvor gammel er du? *

Hvilken klassetrinn går du i? *

Hvilket kjønn er du?

- Jente
- Gutt
- Annet/ønsker ikke å svare

Svar på spørsmålene og påstandene under ved å trykke på tallet som passer best



Liker du å spille digitale spill?

Ikke i det hele tatt — Ja, veldig godt

Verdi

Spiller du ofte digitale spill?

Aldri — Veldig ofte

Verdi

Liker du å bruke spill til å lære?

Verdi

Jeg synes det er gøy å lære nye ting

Verdi

Å lære om klima og miljø er spennende/interessant

Verdi

Jeg synes det er viktig å lære om klima og miljøet

Verdi

Send

Appendix B

Post-Test Questionnaire

Post-test coralQuest

0 %

Obligatoriske felter er merket med stjerne *

Hva er tallet du har fått utdelt? *

Hva var brukernavnet ditt i applikasjonen? *

Alder *

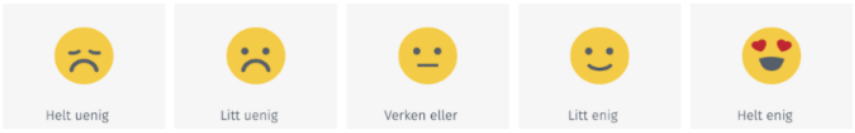
Klassetrinn *

Kjønn *

- Jente
- Gutt
- Annet/ønsker ikke svare

Neste side

Svar på spørsmålene under ved å trykke på det tallene du synes stemmer best



Jeg føler jeg har lært noe nytt etter å ha spilt coralQuest *

Helt uenig Verken eller Helt enig

Verdi

Jeg er mer interessert i å lære om miljøet etter å ha spilt coralQuest *

Helt uenig Verken eller Helt enig

Verdi

Jeg føler meg mer motivert til å lære om miljøet etter å ha spilt coralQuest *

Helt uenig Verken eller Helt enig

Verdi

Jeg synes det er viktig å lære om klima og miljø *

Helt uenig Verken eller Helt enig

Verdi

Jeg kommer til å oppsøke flere informasjonskilder om miljøet etter å ha spilt coralQuest *

Verdi

Hvis jeg hadde hatt tilgang på coralQuest hjemme, tror jeg at jeg ville spilt det mye *

Verdi

Jeg ble forvirret flere ganger da jeg spilte coralQuest *

Verdi

Jeg synes coralQuest var lett å bruke *

Verdi

Jeg ville trengt hjelp fra en voksen til å fortsette å spille coralQuest *

Helt uenig | Verken eller | Helt enig

Verdi

Jeg følte at jeg alltid visste hva jeg skulle gjøre videre mens jeg spilte coralQuest *

Helt uenig | Verken eller | Helt enig

Verdi

Noen av tingene jeg måtte gjøre i spillet ga ikke mening *

Helt uenig | Verken eller | Helt enig

Verdi

Jeg tror de fleste av vennene mine fort ville lært hvordan man skal spille coralQuest *

Helt uenig | Verken eller | Helt enig

Verdi

Noen av tingene jeg skulle gjøre i coralQuest var litt merkelige *

Verdi

Jeg følte meg selvsikker/trygg da jeg spilte coralQuest *

Verdi

Jeg måtte lære meg mange ulike ting før jeg kunne spille coralQuest *

Verdi

Jeg likte godt å spille coralQuest *

Verdi

Hvis jeg hadde hatt mer tid, ville jeg fortsatt å spille coralQuest *

Helt uenig | Verken eller | Helt enig

Verdi

Jeg vil fortelle vennene mine om coralQuest *

Helt uenig | Verken eller | Helt enig

Verdi

Er det noe mer du vil legge til?

Forrige side

Send

Appendix C

Information Letter

Foreldresamtykke for barns deltakelse i forskningsprosjekt "Coral Quest"

Hei! Vi er to masterstudenter ved NTNU som lurer på om barnet ditt kan være interessert i å delta i et forskningsprosjekt? Vi ønsker å finne ut; *"Hvordan kan spillifiserig motivere barn til miljøundervisning i en uformell setting?"*

Formål

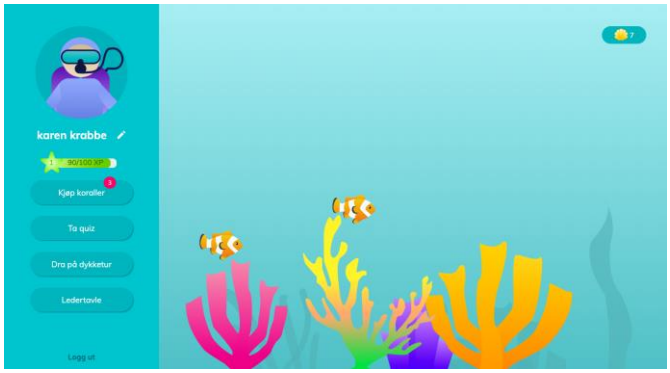
Formålet med dette skjemaet er å gi deg informasjon som kan påvirke din beslutning om hvorvidt du vil la barnet ditt delta i et forskningsprosjekt hvor formålet er å kartlegge hvordan spillifisering (gamification) kan fungere som en motivator i læring om klima og miljø utenfor skolen. Hvis du bestemmer deg for å la barnet ditt delta i denne studien vil dette skjemaet bli brukt til å registrere din tillatelse. Vi håper du, og barnet ditt ønsker å være med!

Hvem leder forskningsprosjektet?

Julie Holte Motland og Karen Dahl Aarhus er masterstudenter innen Informatikk ved NTNU i Trondheim.

Introduksjon til applikasjonen

Coral Quest er en web-applikasjon med formål om å fungere som en motivator i miljøundervisning (og naturfag) utenfor skolen. Korallrev et sentralt tema i applikasjonen og ulike spillelementer, slik som avatar og poeng er implementert.



Brukerne av appen vil møte på ulike oppdrag de kan gjøre for å opptjene poeng, som kan brukes på å gro koraller i et interaktivt miljø og gjøre det mer motiverende/interessant/gøy å lære.

Du kan lese mer om applikasjonen her: https://coral-reef-awareness.web.app/

Skjermbilde fra applikasjonen

Hensikten med studien

Hvis du samtykker, vil barnet ditt bli bedt om å delta i en forskningsstudie om hvordan spillifisering av miljøundervisning kan motivere barn til å lære utenom skolen. I sammenheng med dette har det blitt utviklet en web applikasjon for å teste et realistisk scenario over hvordan spillifisering kan motivere barn innenfor dette fagfeltet.

Hva betyr det for barnet å delta?

Dersom du lar barnet ditt delta i denne studien, vil jeg be barnet om å;

- Bruke appen Coral Quest under et besøk på Vitensenteret i Trondheim.
- Svare på en spørreundersøkelse angående deres motivasjon til læring i miljøundervisning, og om bruk av spillifisert læring og deres holdninger relatert til dette (f.eks. tilfredshet, letthet, vanskelige/lette/utfordrende deler av aktiviteten) både i forkant og etterkant av bruksperioden.
- Barnet ditt kan også bli spurt om å delta i et kort intervju i etterkant av bruksperioden som vil bli tatt opp på båndopptaker. Her vil det være snakk om opplysninger som hva de likte og mislikte ved appen, om de følte seg motivert osv. Dette vil også foregå under besøket hos Vitensenteret.

Dersom du som forelder ønsker å se applikasjonen, spørreskjemaet eller intervjuguiden på forhånd, er det bare å ta kontakt.

Denne studien vil gjennomføres i løpet av en time og i sammenheng med barnets besøk på Vitensenteret. Det vil være mellom 25 og 50 andre barn i denne studien.

Data om deltakernes kjønn og alder vil bli samlet inn ved hjelp av spørreskjemaene, lydopptak av intervju, og data lagret gjennom bruk av applikasjonen vil bli behandlet konfidensielt. Dataen vil bli anonymisert og kan ikke knyttes til deltakerne i studien.

Frivillig deltakelse

Det er frivillig å delta i prosjektet, og du eller barnet ditt kan når som helst velge å trekke sitt samtykke uten å oppgi noen grunn. Det betyr at det er lov å ombestemme seg, og det er helt i orden. All informasjon om deg og barnet vil da bli slettet.

Dine rettigheter

Deltakere har rett til å be om tilgang til/sletting/korrigering/begrensning av personopplysninger, og rett til å sende klage til personvernombudet på NTNU eller Datatilsynet om behandling av personopplysninger.

Ditt personvern

Vi behandler opplysninger om ditt barn basert på ditt samtykke. Alle personopplysninger vil bli behandlet konfidensielt. Kun masterstudentene av oppgaven og veileder vil ha tilgang til dataene (se generell informasjon under). Spørreundersøkelsene vil bli lagret i NTNU Sharepoint i henhold til databehandleravtalen mellom NTNU og Microsoft. Det er viktig å nevne at deltakerne ikke vil være gjenkjennelige i publikasjonen. Prosjektet er planlagt ferdigstilt innen starten av juni 2022, der alle data vil anonymiseres.

Studiet er varslet til Sikt – Kunnskapssektorens tjenesteleverandør, som har vurdert at behandlingen av personopplysninger i dette prosjektet er i samsvar med personvernregelverket.

Generell informasjon

Dersom du har spørsmål angående prosjektet, ta kontakt med:
Karen Dahl Aarhus, e-post: karendaa@ntnu.no, mobilnummer: +47 41079762
Masterstudent ved Institutt for datateknologi og informatikk ved NTNU

Veileder for prosjektet er Sofia Papavlasopoulou, førsteamanuensis ved Institutt for datateknologi og informatikk ved NTNU, e-post: spapav@ntnu.no, adresse: Sem Sælands vei 9, IT-bygget * 146.

Personvernombud ved NTNU (Thomas Helgesen, thomas.helgesen@ntnu.no)

Hvis du har spørsmål knyttet til Sikt sin vurdering av prosjektet, kan du ta kontakt med:
Personverntjenester ved SIKT på epost (personverntjenester@sikt.no) eller på telefon: 55 58 21 17.

Foreldresamtykke for barns deltakelse i forskning

Jeg har mottatt og lest informasjon om prosjektet *Coral Quest* og samtykker til mitt barns deltakelse i forskningen.

Barnets navn: _____

Forelders navn:
_____

(Signert av forelder, dato)

Appendix D

Interview Guide

Intervjuguide - semi structured interview

Samle data: lydopptaker

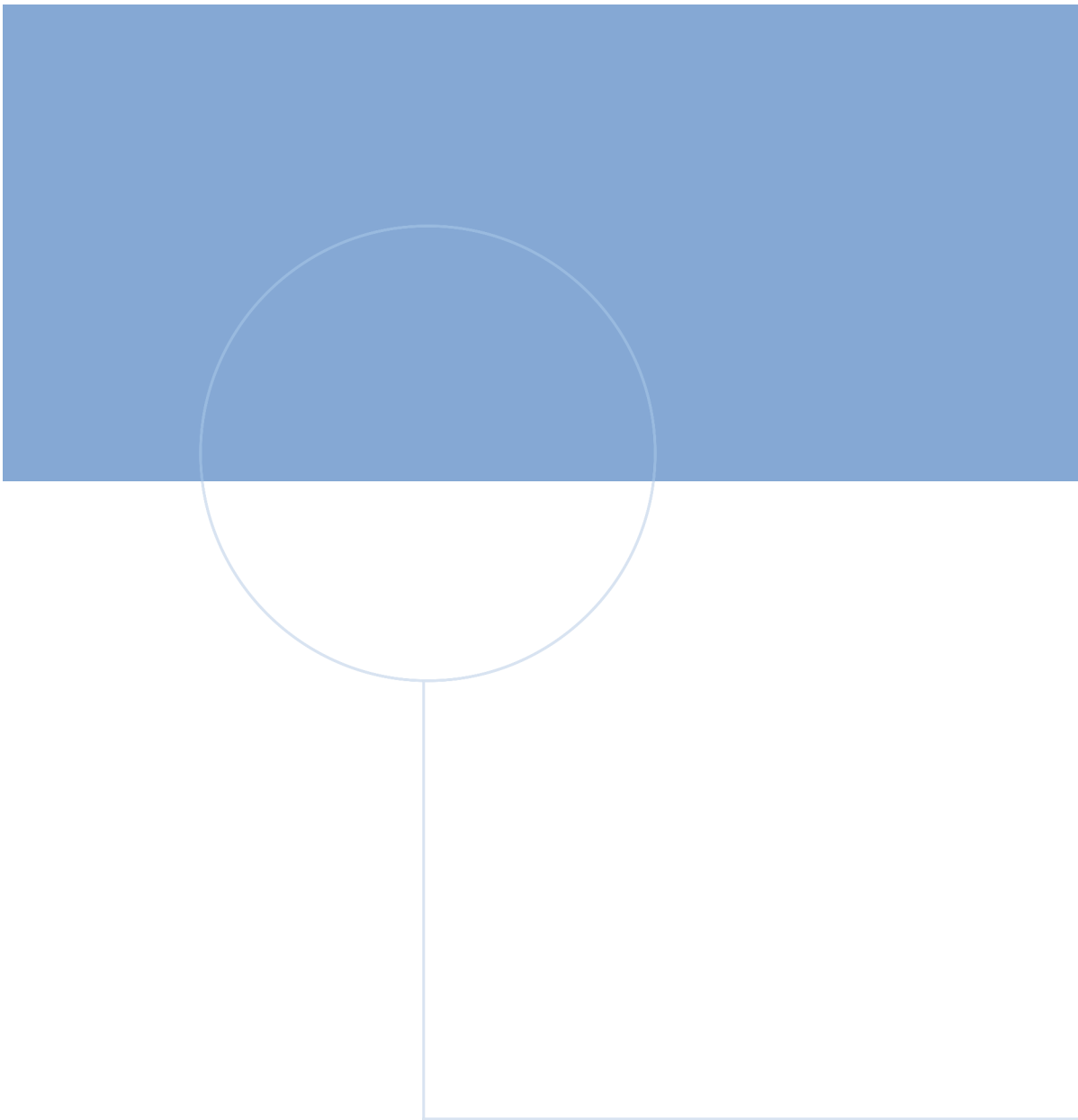
Husk: stille åpne spørsmål og oppfølgingsspørsmål der det passer

Kan starte med: stille ikke-forskning-relaterte spørsmål om barnets fritid, hobbyer elns. eller hvordan det har vært på vitensenteret

Spørsmål:

- Hva synes du om coralQuest?
- Følte du at du lærte noe nytt?
    - Hva lærte du?
- Hva synes du var det beste med coralQuest?
- Hva synes du om å lære om klima og miljø?
    - Følg opp med hvorfor/hvorfor ikke/oppfølging
- Ville du likt å bruke applikasjonen mer?
    - Hvofor/hvorfor ikke?
    - Hvor ville du brukt applikasjonen? (hjemme/skolen etc. la de svare)
- Hvilke deler av appen likte du best? Hvorfor?
- Hva syns du om fargene og animasjonene i appen?
- Hva likte du ikke ved appen?
- Hva kunne gjort appen bedre?
- Hva synes du om ledertavlen?
    - Hvilken ledertavle fulgte du mest med på?
- Hva synes du om krabben?
    - Leste du det krabben sa? Hvorfor/hvorfor ikke?
    - Hvis ja - var det nyttig?
- Hva synes du om å tjene sanddollar og kjøpe koraller?
- Til slutt, er det noe mer du ønsker å legge til/si?

Avslutte intervjuet:
Siden deltakerne er barn, er det nødvendig å holde intervjuene korte for at de ikke skal miste interesse, og for å ikke miste verdifull informasjon som følge av det.



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