Opportunities of digital environments for informal science education

A RESEARCH PROJECT IN SCIENCE COMMUNICATION

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Abstract

The present project's goal is to design, develop, test, and evaluate a digitalized blended learning module about the ocean batteries and energy farms of Ocean Grazer, a project that the University of Groningen has initiated. Therefore, a digital environment that could be implemented for teaching the main aspects of 'Ocean Grazer' in an interactive and collaborative manner was produced using Gather (www.gather.town). Here, user can freely move his avatar in several rooms of the energy farm and engage collaboratively with peers and instructors about features of the energy farm through inquiry-based activities.

To find out what opportunities a digital environment offers for informal science education about the Ocean Grazer project, the developed environment was pilot tested. This was done by conducting a discussion-based interview (n=3) in which the six asked questions were based on aspects from Moore's educational framework. After conducting the interview, data was analysed using the grounded theory approach.

Based on these findings, it could be said that this digital environment offers a good starting point with various opportunities for informal science education about the Ocean Grazer project. However, there are a number of shortcomings that need to be resolved before putting the environment to use. With Moore's educational framework in mind, further iterations of the environment should include more necessity for intellectual processes in order to aid informal science education.

Background

According to Takahashi and Tandoc (2016), the importance of having knowledge about science and technology has increased in the current era of digital information overload. The same applies to understanding what contributes to scientific learning. This can include sources of information, as well as trust in those sources (Takahashi & Tandoc, 2016). These researchers found that interest in science can directly predict scientific knowledge. Furthermore, interest can have indirect effects on knowledge by affecting internet use, confidence in the press, and the perception of scientists. Besides, distrust of news sources helps with learning about science (Takahashi & Tandoc, 2016).
According to Bucchi and Saracino (2016), images are put at the centre of science communication since the beginning of modern science. This is especially the case in this era of digital communication. These researchers found that a representative part of the Italian population fare generally better in recognizing science-related images than in responding to written questions. This means that the use of images could aid greater public engagement with science and the findings that emerge from it (Bucchi & Saracino, 2016).

Educating student teachers to acquire Information and Communication Technology (ICT) skills has been a continuous goal for teacher education the last decades, reflected in recent STEM Education reforms as well (NRC, 2014). Hence, a lot of research has been done to articulate guidelines and recommendations for future teacher preparation ICT programs. First, it is important that the emphasis should be shifted to the context and the pedagogy that ICT are embedded rather from the technology itself (Prestridge, 2017). Learning *with* technology rather than *about* technology is a crucial idea to make efficient use of ICT (Waight & Abd-El-Khalick, 2007). For instance, the concept of Making is being increasingly implemented in educational practices. Making refers to the practical use of technologies like electronics, 3D printing, and programming in order to create technology-based artifacts (Schlegel et al., 2019). Making could be associated with play, innovation, and intrinsic motivation (Dougherty, 2013), as well as technological literacy. Schlegel et al. (2019) studied the effects of integrating Making into existing educational systems, focussing on whether engaging in Making changed self-efficacy, interest, and identification with Making, as well as science. The study showed that exposure to a Making-based science curriculum significantly increased Making self-efficacy, science self-efficacy, science identity, and STEM possible selves. Based on these findings, it could be said that Making can promote the development of self-efficacy and STEM possible selves at an early age, of which both identities have potential in shaping future choices (Schlegel et al., 2019).

If teachers align the use of technology with specific instructional objectives and with learning science content, it will be more effective (Bell et al., 2013) and it will be more likely to use them in the future. This way, teachers are given the chance to develop Technological, Pedagogical and Content Knowledge (TPACK). TPACK is the type of knowledge which takes into consideration the complex interplay of the three cognitive domains: technology, pedagogy and content and is the basis for good teaching with technology (Koehler & Mishra, 2006). Results from a 2012 study by Lin et al. (2013) showed the seven-factor model for the knowledge of teachers, as designed by Mishra and Koehler (2006), to be right. The researchers showed that science teachers' synthesized knowledge of technology, pedagogy, and content (TPC) are significantly and positively correlated with the other factors of the model. Among these TPACK factors are technological knowledge (TK), pedagogical knowledge (PK), content knowledge (CK), and combinations of these factors. Furthermore, Lin et al. showed that especially female science teachers feel more self-confident in PK and less self-confident in TK than their male colleagues. These perceptions of TPACK factors were significantly and negatively correlated with the age of the female teacher (Lin et al., 2013). Regarding the pedagogy, research stands up for a student-centred approach, where ICT tools facilitate the inquiry process or are part of it, instead of just being used in a passive manner, reflecting traditional teaching practices, like using ICT for word processing, reading texts or personal communication(mail) (Odom et al., 2011; Prestridge, 2017). The roles of the students in interactions and the manner and the extent of the teacher involvement, teacher beliefs and the general classroom layout also play an important role in a rather holistic stance (Waight & Abd-El-Khalick, 2007; Prestridge, 2017).

Concurrently, experiments are significant means to foster learning science content and methods of science inquiry (Duit & Tesch 2010). When combined with ICT tools like microcomputers, i.e., electronic sensors and devices which, with the aid of the appropriate software can real-time visualize and graph phenomena, a dynamic learning environment is formed (Sokoloff et al., 2007). More recently, these laboratory environments are also implemented through online virtual modalities through the development of virtual labs (Heradio et al., 2016). Additionally, other digital technology tools also include virtual and augmented reality (VR and AR) environments (Ibáñez & Delgado-Kloos, 2018), interactive whiteboards (Ormanci et al., 2015), and educational robotics (Eguchi 2017). For example, two types of AR could be distinguished, i.e., image-based AR and location-based AR (Cheng & Tsai, 2013). The former seems to facilitate better spatial ability, practical skills, and conceptual understanding, while the latter usually supports inquiry-based scientific activities (Cheng & Tsai, 2013).
Hu-Au and Okita (2021) aimed to study what differences in learning results and safety behaviours when conducting a chemistry laboratory experience in VR or real life. This study showed that learning general content knowledge, laboratory skills, and safety behaviours related to procedures were comparable between VR and real life conditions. However, clean-up behaviours were showed less frequently in VR conditions. Learners also elaborated and reflected more on general chemistry content and laboratory safety knowledge in the VR environment. This could be due to the exploratory and risk-free nature of a VR environment (Hu-Au & Okita, 2021).

Recent trends in science education, as well as needs that derive from accessibility, flexibility or emergency issues (e.g., the recent pandemic), call upon mixed modalities of face-to-face and distance learning courses, which is also called 'blended learning' (Margulieux et al., 2016). In particular, according to Margulieux et al. (2016), several modalities can emerge from the combination of delivery of content via Instructor/Technology and by receiving/applying content. Examples are: a) combination, courses that provide instructional support during both receiving and applying content, either by face-to-face or online combination form, depending on how instruction is been delivered, b) hybrid, courses that combine delivery of instruction via an instructor and via technology; that can be in a lecture hybrid or a practice hybrid way, depending on what type of instruction is delivered and c) blended, courses that combine delivery via an instructor and via technology and provides instructional support during both receiving and applying content.

Ocean Grazer

In 2015, all Member States of the United Nations (UN) adopted 'The 2030 Agenda for Sustainable Development' (United Nations, n.d.). The agenda is a directory on how to create and maintain peace and prosperity for people and the planet. It provides an urgent call for action, assembled in 17 Sustainable Development Goals (SDGs). One of these goals aims at ensuring access to affordable and clean energy for all (United Nations, n.d.).

One project that focusses on the production and storage of renewable energy, is the Ocean Battery of Dutch clean technology start-up Ocean Grazer (Ocean Grazer, n.d.). The technology aims to generate offshore renewable energy by improving the efficiency of offshore wind farms and increase the energy yield per square kilometre (University of Groningen, 2022). The unused potential of offshore renewable energy could be unlocked by combining, for example, wind, solar, and wave energy at a specific location of deployment. These energy sources can be combined within hybrid devices that also feature energy storage on that specific location (University of Groningen, 2022).

According to Ocean Grazer, the amount of energy generated offshore will exceed 1150 gigawatts by the year 2050, which is about 25% of today's total power generation capacity worldwide (Ocean Grazer, n.d.). Weather conditions will increasingly cause large fluctuations in the production of renewable energy. Oversupply might eventually create a big market for large scale energy storage. By deploying it at the source of power generation, the Ocean Battery can manage the flow of electricity through the grid and balance supply and demand (Ocean grazer, 2022a).

The Ocean Battery consists of multiple parts, among which are a pump and large bags that are placed on the seabed (Vels, 2022; Ocean Grazer, 2022a). In case of an overproduction of energy by wind turbines, the surplus of energy will activate a pump. Water is being pumped from rigid underground reservoirs, which can hold 20.000 m^3 of water under low pressure. The water is then pumped into large flexible bags, where it is stored under high hydrostatic pressure of the ocean in the form of potential energy. Each pump is linked to four reservoirs and four bags, which means that each system can pump a total 80.000 m^3 between the reservoirs and the bags (Ten Brinck, 2022; Ocean Grazer, 2022a). When demand for energy increases, the bags will be emptied under pressure. The water flows through large hydro turbines, which generate up to 10 MWh per system of four reservoirs and four flexible bags (Vels, 2022; Ocean Grazer, 2022a). Furthermore, the Ocean Battery reportedly has an efficiency of 70% to 80%. This should make it a direct competitor for hydrogen-based solutions, since the conversion of electricity to hydrogen takes place with an efficiency of about 75% (Horlings, 2018; Ocean Grazer, 2022a).

The Ocean Battery is said to be highly modular. The storage system can consist of several connected, stand-alone units, allowing the system to grow along with the capacity of the wind farms by adding units as a wind farm expands (Vels, 2022; Ocean Grazer, 2022a). Ocean Grazer also claims that the Ocean Battery is highly sustainable and that it can enhance marine life (Ocean Grazer, 2022a). With the batteries embedded in the seabed, fishery and other human activity would become difficult to execute. This could artificially create safe spaces for marine life to rebuild previously destroyed habitats (Ocean Grazer, 2022). Furthermore, the Ocean Battery will be made without using any rare earth materials and Ocean Grazer aims to create a circular economy with the used materials. The system will be made from steel, concrete, rubber, and PVC, which are all readily available all over the world. The materials will be produced by local partners of Ocean Grazer in an attempt to minimize the emissions of greenhouse gases and therefore the environmental impact (Ocean Grazer, 2022a). Reportedly, the only rare earth material used in the system will be the used in the pumps and turbines, which might contain copper and permanent magnets (Ten Brinck, 2022; Vels, 2022).

Project description

The goal of the present project was to design, develop, test, and evaluate a digitalised version of a teaching scenario in the context of alternative and eco-friendly energy sources & storage devices. In specific, the project focussed on recent innovative work that has been developed for ocean batteries and energy farms for stable energy production and storage, a project that University of Groningen has initiated. In this light, a blended learning module on ocean batteries has been developed for preservice teacher training in the context of Sustainability goals (United Nations, n.d.).
Therefore, a digital environment was needed that could be implemented for teaching the main aspects of 'Ocean Grazer' in an interactive and collaborative manner. Initial ideas for this related to a digital platform in which users can freely move their avatars in several 'rooms'/modalities of the energy farm. Users should be able to engage collaboratively with peers and instructors about features of the energy farm through inquiry-based activities.

The developed platform was pilot tested by master/PhD students in science/STEM education and communication (n=3) who acted as experts. Data were collected and analysed regarding this first draft of the digital platform.
Findings of the research are prospected to contribute to recommendations for further versions and iterations of the digital environment. This will be done by answering the following research question: "What opportunities does a digital environment offer for informal science education about the Ocean Grazer project?"

Materials and methods

The design

The first draft for the digital environment was designed in Gather. Gather is a video chat platform designed to look like a videogame. Users can create their own rooms, buildings, or even entire towns in order to make their digital meetings more immersive. Users can walk freely through their digital world, approach one another, and interact with objects and other users within the environment. Gather has the option to fully design several rooms based on your backgrounds of choice, which makes it a suitable candidate for designing a digital learning environment around the Ocean Grazer project. To accommodate interactivity and collaboration between the users, the choice was made to implement the general gameplay of an Escape Room; a puzzle tour in which students in small groups solve a series of puzzles step by step in order to reach the end. This not only introduces the students to the project in an easy and challenging way, but also encourages them to investigate on their own and to cooperate with their classmates.

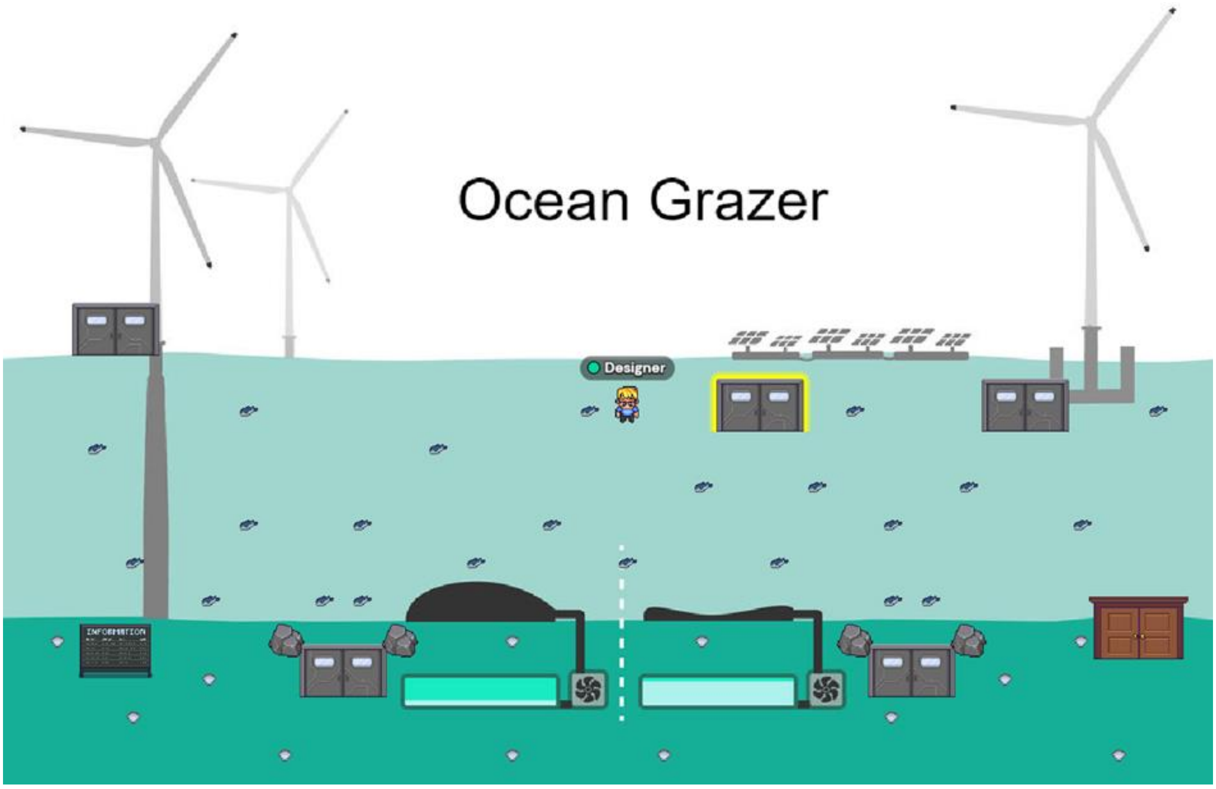

Figure 1: Entrance of the digital environment

A total of five rooms were designed, of which the last 3 are behind door that are locked with a certain code. The first room (Entrance; figure 1) shows a schematic overview of how Ocean Grazer would look like in general. This room houses the doors to all other rooms, as well as the initial instructions for playing the Escape Room.

Figure 2: Wind turbine room

The second room (Wind Turbines; figure 2) houses the introductory video on Ocean Grazer (2022b), as well as several pieces of relevant information and questions (Appendix 1 and 2) that will help the students find the code to the next room.

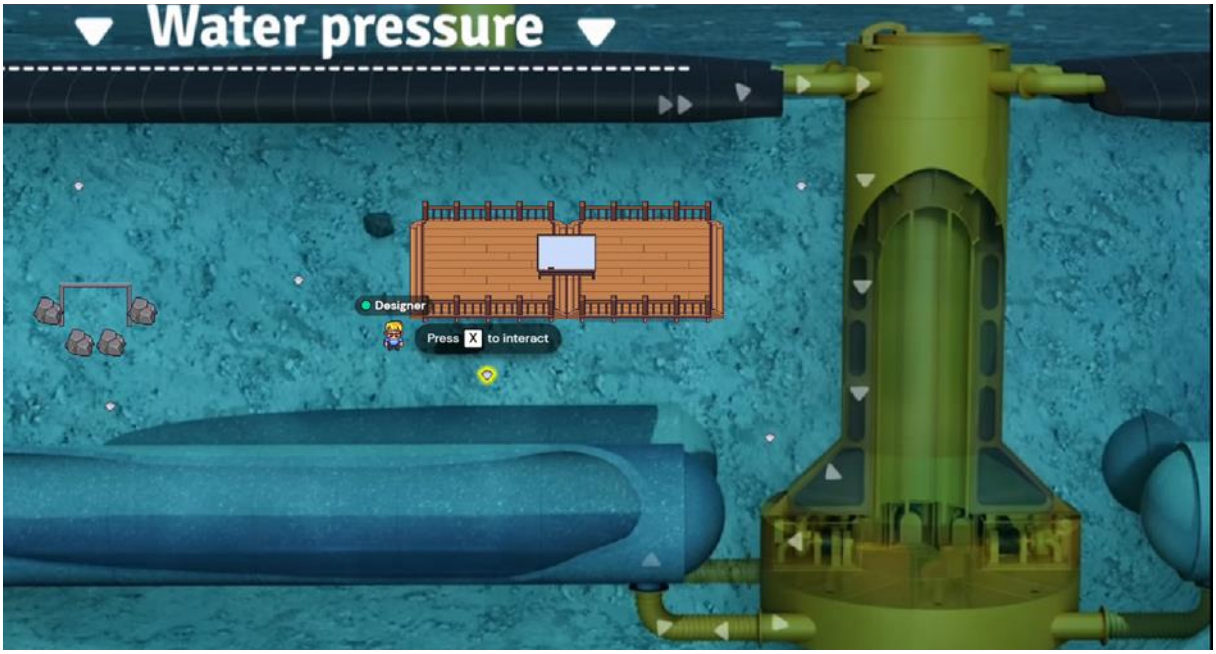

Figure 3: Ocean Battery room 1

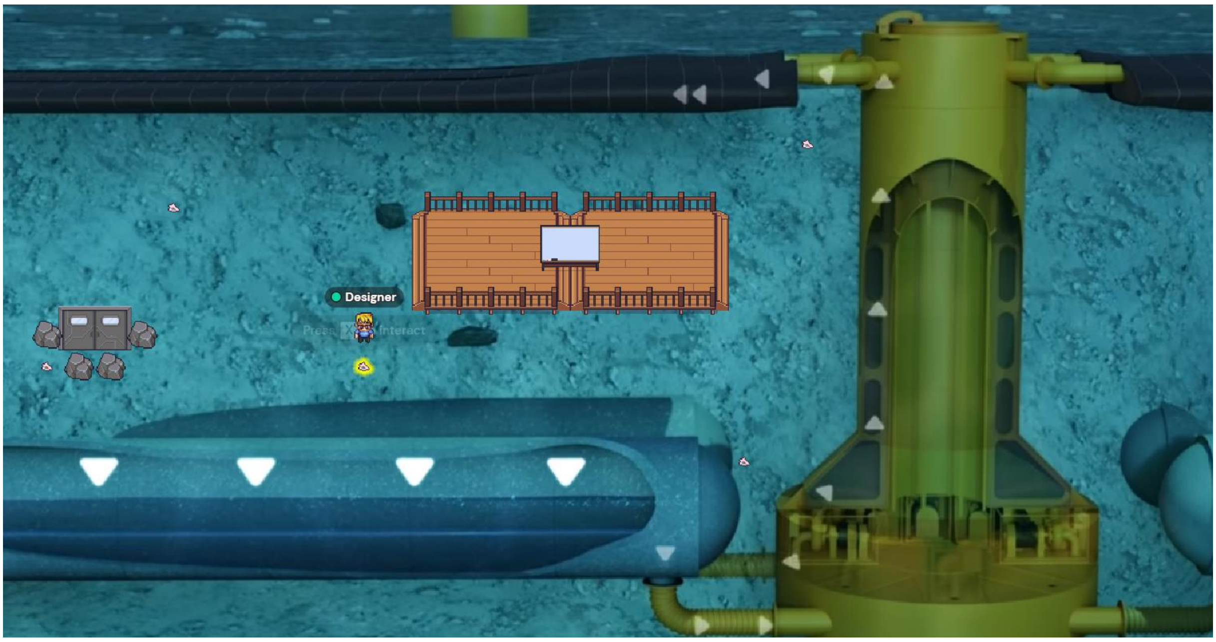

Figure 4: Ocean Battery room 2

The third and fourth room zooms in on the actual ocean battery (figures 3 and 4). The rooms again house several pieces of relevant information and questions that will lead to new codes for the students to use (Appendix 1 and 2).

Figure 5: Final discussion room

At the end, in the fifth room, students are congratulated with finishing the Escape Room (figure 5). Here, the students get some time to reflect on what they have learned from the Escape Room and what it means for society and the environment. A guiding educator, who will always be present during a playthrough, will lead this reflection by asking the students some questions. This educator can also give students hints whenever they get stuck

The interview

To evaluate the draft for the digital environment, a pilot test was done by conducting a discussion based online interview with a total of three participants. The participants included 1) the designer of the digital environment (master student in Science Communication and writer of this report), 2) a STEM researcher, and 3) a teacher educator. Participants were selected for their expertise on the topic. During the interview, the following six questions, based on Moore's educational framework (Moore et al., 2014; Moore et al., 2017) were discussed:

1. To what extent do the activities relate to real-world contexts? What other suggestions do you have to highlight this aspect? (Real-world relevance/problematization)
2. To what extent does the module engage participants in the engineering design practices, e.g., designing/testing/evaluating/revising (digital) artefacts/prototypes? What other suggestions do you have to highlight this aspect? (Engagement in Engineering design cycle)
3. To what extent does the module include activities to explicitly emphasise interdisciplinarity? What other suggestions do you have to highlight this aspect? (Interdisciplinarity)
4. To what extent does the module engage the participants in reflections and discussions about the impact of the relevant technologies on society? What other suggestions do you have to highlight this aspect? (Impact on Society)
5. To what extent does the module include reflexive discussion on conceptions of Engineering thinking and practices and/or S-T-E-M practices in general? What other suggestions do you have to highlight this aspect? (Epistemological reflection)
6. To what extent the module provides opportunities for collaboration and teamwork? What other suggestions do you have to facilitate teamwork in the activities? (Teamwork)

Each participant had 2 minutes to share their thoughts on these questions. The entire interview was recorded with consent of all interviewees. For the recording, a screen recorder was used. A transcription of the interview was initially produced using otter.ai software, after which it was revised by the researcher. The interview was analysed using the grounded theory approach. The six questions correspond with six topics derived from Moore's educational framework. For the analysis, the responses of each interviewee per topic were divided into three different categories, namely 1) potentials, 2) deficiencies, and 3) suggestions. Per topic, any points of agreement and disagreement between the interviewees were summarised.

Findings

Real-world relevance/problematization

Potentials

The designer tried to implement real-world relevance by stating facts about Ocean Grazer (2022a), although this information was limited, and using numbers from Statistics Netherlands (CBS, 2021). The digital environment appears to be highly related to the context of wind turbines, green energy, and the climate.

- *STEM researcher: "I agree with the designer that it's good that they also brought the local dimension about the Netherlands and of course itself, it's very context related with wind turbines and energy crises."*

Deficiencies

The environment offers little context for the students to really relate to. It offers little information about the necessity of the project, which could be added at the start or before entering the digital environment.

Suggestions

It was suggested that there could be an introductory room where a problem (in this case climate change and limitations of renewable energy) is highlighted or discussed to which Ocean Grazer then presents their solution.

- *Teacher educator: "Maybe place a little more emphasis in the beginning on the context of the problems before they start going through each subtopic."*

With this, the digital environment tells the students why scientists pay attention to this problem and why Ocean Grazer exists.

Engagement in engineering design cycle

Potentials

When looking at engagement from a general perspective, the environment was found to be very engaging. The designer added multiple ways for students to engage with the environment through different objects. This was picked up by the other interviewees. For them, the fact that the students have to interact with the environment in order to find information, hints, and pieces of puzzles showed a certain degree of general engagement. They thought that the environment was easy and intuitive to use for youngsters.

Deficiencies

There was no direct form of engagement in the engineering design cycle implemented, apart from the simulation where students have to design their own wind turbine.

- *STEM researcher: "There's a lot that can also be done digitally. But if not, I consider it also good to make the wind turbine simulation have an external link. And we need the mental or intellectual process to be done somehow. Even though it is not possible through the platform, maybe there can be like a link for this."*

Suggestions

It was suggested that students should have more moments in which they have to brainstorm, find some solutions of their own and do their own research. Use of internet could become an activity as well. The simulation could also be combined with some inquiry scaffolding to make them relate to why a certain factor affects the efficiency. This could cause them to relate with the scientific content. The use of an educator was also suggested. This educator could facilitate the intellectual processes of the students by assigning tasks, giving hints, and grading the answers of the students.

- *Teacher educator: "Maybe what will be fun is to let them do some research on their own as well. And for example, you can use the whiteboard, and then you can give them a very broad question. And then they can use one of these digital tools, they can kind of showcase what their answer is, or how they did research. And if there is an educator around, maybe the educator can then give points to the whiteboards. And that included in the code. Like if there is an educator, then let's make use of them, and maybe assign a few more tasks to it."*

Interdisciplinarity

Potentials

Although several disciplines are implied with the technology of wind turbines and the entire Ocean Battery, the designer did not implement explicit interdisciplinary details. It was found that calculations implemented into the puzzles had a scientific meaning.

- *Teacher educator: "Windmills are very disciplinary from their nature, right? So, you have physics, but you automatically have math, you have biology, you have environmental sciences. So, all the topics that you have are actually in fact, interdisciplinary."*

Deficiencies

No real deficiencies were mentioned on the topic of interdisciplinarity.

- Teacher educator: *"Now, it's just a matter of highlighting each discipline within that, so I think you're almost done."*

Suggestions

To implement more interdisciplinary aspects, it was suggested to let students think, for instance, about offshore wind turbines from different perspectives. They could think about pros and cons of placing wind turbines offshore from environmental and social perspectives. It was also suggested to implement more explicit activities and questions about engineering. For instance, students could be asked to think about a question on a relevant topic. They then should state how they would answer that question themselves, how an engineer would answer, and how an animal would look at the question. This could provide interesting points for further discussions. Last suggestions included implementing environmental details, since Ocean Grazer states that the battery could provide a safe space for ocean life to thrive (Ocean Grazer, 2022a). Furthermore, connections with social sciences could be made, since people also have an impact on topics that are relevant for the Ocean Grazer project.

- *STEM researcher: "What I would suggest is that there should be more explicit activities for the students to really reflect on the similarity. So, I mean, there should be some part or several activities or questions on reflecting on the similarities in order to make it more understandable for children. And also engineering, there are also several aspects, for example, through the simulation can also be discussed. Why should we put like windmills in the offshore? Why not in the hills? What pros and cons are there, you know, by the environmental or social impact of them? […] What I always like for interdisciplinarity, is take one topic. So, for example, ask a question about windmills. And then just say to the students: how would a physicist answer this* *question? And now how would you as a person answer this question? And how would an animal look at this question, you know, and you automatically already get very cool, interesting, different answers? Which is all brought together by the topic that you use?"*

Impact on society

Potentials

For this aspect, the designer only highlighted that there were opportunities to have a talk about Ocean Grazer and its possible impact in the final room. This room was meant for discussions. For the other interviewees, this aspect appeared to have a lot of overlap with the question on real-world relevance. It was highlighted that there are some aspects that are very much connected with society.

- *STEM researcher: "It is not explicitly addressed so far, but it can be highlighted more. And it can be in the beginning as well, but also as a reflection at the end. And in the simulation as well. There are some aspects that are very much connected with society, like, you know, this parameter may increase efficiency, but on the other hand, it is worse for the public because for some people, it ruins the aesthetic of the places and stuff like this. There are many opportunities for sure."*

Deficiencies

The role for the impact on society was not very explicit.

Suggestions

It was suggested that the students should discuss about this topic as well. The educator could rate the students' arguments based on how many different points of view they could realise other than their own opinion. Furthermore, it was suggested that the educator could give the students a letter for each argument they bring up. With the letters, students can then guess the codeword they need to progress.

Epistemological reflection

Potentials

No real potentials were mentioned in this part

Deficiencies

There seemed to be few opportunities for reflexive discussion on conceptions of engineering thinking and practices or S-T-E-M practices in general.

Suggestions

This question only has lead to suggestions on how to implement this. It was suggested to let the students think about what an engineer does and what constraints like maximum efficiency, cost, impact on society, and limitations by nature the engineer addresses. The underlying question should be: *"How could this environment let the students realise what an engineer actually does and what he experiences in life?."* Students should know how someone becomes an engineer and realise how engineering really works. It was suggested that there should be an in-game expert. Students could ask the expert questions about what they can and can not do as an engineer, e.g., because of time or cost restrictions.

Furthermore, it was opted to let them experience the real context an engineer works in and to let them understand it is applied science and not just theoretical.
It was also suggested that it would be too easy when the educator just gives the students the right answer when they are stuck. However, specific tasks may require more preparation time from the educators, which should not specifically be necessary. It was suggested to give the students an engineering task instead. The game may require them to design something, this could be something like a chair or something else they are familiar with. The students then have to consider functionality versus cost or other scenarios. Then they have to think about the design, materials, the time they have to design it and for how many persons it would be. It was thought that this could be very intuitive for the students, so there would be no need to make it very difficult.

Teamwork

Potentials

The designer tried to implement teamwork with use of the whiteboards in the digital environment. The idea was that students could use these to gather all information and hints in one place. The students could collaborate here when trying to answer the questions. Furthermore, the idea was that one student would have to walk back to find the information needed to answer a question in a later room. Other forms of collaboration were found during the interview as well. The environment seems to offer some difficulties, but in a positive manner. Just like in the real world, students need to be close to each other to be able to interact and discuss certain things. They can also cause obstructions for one another since they can not pass through each other. On top of that, items can be set to have a minimum required proximity for the students to interact with them, but also have limited approachability. This requires the cooperation of various students in order to work efficiently.

Deficiencies

It was noted during the interview that it is difficult to predict what students will do based on this prototype. It was imaginable that someone could do it without collaboration.

- *Teacher educator: "This is just a case of having a pilot study and figure out what students will do. I think this is very difficult to predict based on what you have so far, because I can imagine that if you are by yourself, because everything is quite close to each other in each room, right? So, I think if you just run around all by yourself, you will still manage to do things."*

Suggestions

No suggestions were made for this topic

General remarks

In the interview it emerged that the environment was highly immersive, fun, useful and full of potentials. It was also found to be good that the voice chat was not like standard video conference software where everyone can act at the same time and interrupt each other. Negative points were that competition between different groups at the same time is hardly feasible with this software and that there was a lack of time restrictions, like in a real-life escape room. To improve parts of these negative points, it was suggested that time should be measured during the entire game for each group. Shorter durations should then be awarded more points at the end. This could be motivating to assign different roles or tasks and hence aids collaboration. Furthermore, the fact that students have different types of knowledge and skills could be beneficial for collaboration as well.

- *Teacher educator: "I am very excited about this. I think it is very smart to do a digital escape room very appealing. And the platform looks great. Yes, so compliments for that. You can see it as a basis. And now you can revise it a bit more with the questions. We just discussed implementing all those things. But I think this platform is amazing. Yes, very easy to use. Right. And that makes it a very attractive tool as well."*
- *STEM researcher: "For me, it is also like, it is fun. It is useful. It certainly has a lot of potentialities, we will have to consider like in future iterations, how to do special diverse activities, you know, to also implement other stuff."*
- *Designer: "Apart from that the program is indeed quite easy to use and attractive to see. It could be a bit buggy sometimes. So sometimes the doors do not work. You just get teleported to a completely different part of the room and then you are stuck. But that that is just the earth of the program"*

Discussion

Based on this interview, it could be said that this digital environment is highly related to the context of wind turbines, green energy, and the climate, but offers a limited amount of context for the students to really relate to. It offers little information about the necessity of the Ocean Grazer project, which could be added at the entrance or even before entering the digital environment.

For further iterations, it would be a good idea to implement some forms of intellectual process. It would be good to let the students do some research of their own and formulate their own solutions to broad questions. A guide or educator could facilitate this by assigning tasks, giving hints, and grading the answers of the students. This provides opportunities to improve the engagement in the engineering design cycle.

It was found that the environment already implements interdisciplinarity very well, but the focus could lay a bit more on this. The topic of interdisciplinarity also provides opportunities for adding extra thinking steps for the students. This would aid the intellectual process as well.

It was thought that, in further iterations, an educator can rate the answers of the students or even the points they made during a discussion. It would be a possibility that every good argument would be awarded a piece of the next code. Connections with society can be made via various ways. For instance, the environment could contain a question or puzzle for which students have to weigh parameters that affect efficiency against aesthetical arguments from the general public.

It was found that Moore's educational framework (Moore et al., 2014; Moore et al., 2017) could be implemented more into the environment. Also, steps could be made to implement more reflexive discussions to let students think of what an engineer actually does and how engineering really works. Possibilities for this matter are highlighted in the results section for this topic.

The few opportunities for collaboration are found to be generally good, although collaboration is not directly needed in this specific prototype. The mechanics of the platform add to the immersion, which means that it feels like the real world since parts are not passable and you need to be close to each other in order to interact. However, it would be difficult to predict what students would do when they have to engage in this digital environment. A pilot study with students will be needed.

Based on these findings, it could be said that this digital environment offers a good starting point with various opportunities for informal science education about the Ocean Grazer project. However, there are a number of shortcomings that need to be resolved before putting the environment to use. With Moore's educational framework in mind, further iterations of the environment should include more necessity for intellectual processes in order to aid informal science education.

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Appendix 1: transcription of the interview

Designer:

So, the first question was, to what extent do the activities relate to real world contexts? What other suggestions do you have to highlight these aspects? So, for me, I tried my best to add a bit of real world information so in the turbine room, I added some information on the offshore wind turbine numbers for the Netherlands. In the battery rooms, both of them I used the information I could find from Ocean Grazer themselves, so it's all based on facts and numbers from the Netherlands and from the ocean grazer project itself. At least I tried to.

Teacher Educator:

I think the content so far, it's, it's a little dry. So, is it a possibility to maybe give a bit more context to why they are doing these topics? You know, like, it all has to do with sustainability and the climate and everything, like sustainable sources. So maybe if you had you in the beginning of each room, sketch a little bit more the problem of why we are doing this, why we are doing science in these topics. Maybe that's that makes it because you give them context, and you give them numbers, but not necessarily context that they can relate to directly.

Designer:

I tried to implement a bit of that by adding the original video from ocean grazer in the first room.

Teacher Educator:

Yeah. Yeah. In the second room, for example.

Designer:

Yeah, it's all connected to that to that video. So

Teacher Educator:

yeah, so that case, maybe because the video is great. So maybe to another thing that they can interact with regarding that topic like place, a little more emphasis in the beginning on the context of the problems before they start going through each subtopic.

STEM researcher:

yeah, yeah. Are you done? Yes. In general, I think two minutes each of us is great. I agree with the teacher educator. I was thinking of future iterations of the project no talking about your task in talking about this project in general. In future iterations. It would be good also to have like an introductory room. So, a room where they discuss and understand the problem and then the ocean grazer comes with the solution. So they can be like a prerequisite room, specifically about the necessity of this. But I agree with the designer that it's good that they he also brought the local dimension about the Netherlands and of course itself, it's very context related wind turbines energy crisis. It's very related.

Designer:

so basically, what an idea could be is like with the other you don't know this, but with the other Escape Room I partly designs was that they, the students start in a sort of presentation room with an educator, and then they head into the escape room. Yes,

STEM researcher:
exactly. Yeah. I think that the first room can also be like a bit a bit of riddles just the focused on the on the necessity of such technology. Yeah. Yeah. Let's move to the second question.

Designer:
Yes. Let's see. That is to what extent does the module engage participants in the engineering design practices? Example given designing, testing, evaluating, revising, digital artifacts or prototypes? And what other suggestions do you have to highlight this aspect?

Teacher educator
Okay, well, it's already engaging right so they have to not only that they can move but I have to search I think that you did have really smart also with the blocking behind the wind turbine. Apart from that, it's mostly pressing X, and then talk with your peers, and trying to solve it, because I saw that they're also games, and you have like a whiteboard, but you don't. And you say, okay, you can use it, but there's not really a nice to use it, I guess, where you don't make it necessary to use it. So, I think it could be even more engaging to play a little bit with the various types of artifacts that are possible within this platform.

Designer:
Yeah, the games in Gather are pretty standard like scribble IO, poker or other kinds of games, just fun games of what those are. So that would not be possible but further iterations could indeed add a little bit more interaction between the students themselves. Let me have a look.

Teacher educator
Can you I don't know if it's possible. But is it possible to require for example two different students to be in two different places before you can do something else that they really have to work together like literary in the space is that possible?

Designer
I don't think so the possibilities of locking of rooms and do other things separately are pretty limited. So the I was I was happy that the doors password doors existed In this program, but I don't think that there is a huge amount of possibilities and gather

28:41
Okay, well in that case you did a great job they have to hook around and also that I like it that you that they thirst for example see question three are the first one to code and that they then have to look further you know, I think yeah, that's great. And it's very simple, it's easy to use as well as very intuitive what to do, especially for youngsters because they are basically indulged in digital environments

STEM researcher
Yes. Designer, do you have something else

Designer
Well, I think this simulation adds to the to the engagement and designing parts of the module. They really have to achieve a goal with the wind turbine simulation and yeah, well, Teacher educator also said That the interactions with different objects and the information and codes and doors and the little private room, sometimes they add to the engagement.

STEM researcher
Yeah. Yeah, there's a lot of, I think, can be done also digitally. But if not, I consider it also good to have like, you know, like the wind turbine simulation have like an external link. And we need the mental process, intellectual process to be somehow done. Even though it's not possible through the platform, maybe it can be like a link of this. You, I would suggest that in this platform, there will be more like some aspects like brainstorming, so the students can be called upon to think of some solutions themselves, or also do their research for themselves. I mean, you said that it's not possible to it's not permitted to visit the internet, but I think it could be an activity, you know. I mean, some practices like to do their own research about solutions, or brainstorming would be nice. And also like the simulation, it's very nice, I said before, to also be combining with some inquiries scaffolding, to make them to relate them to why this factor affects the efficiency, so to relate with a science content related. But yeah, it has, the simulation was really nice. And it can be also some similar stuff in other stages. Okay, great. Let's go to the third one.

Teacher educator
One question, what happens if they don't find the right answers aren't in stock forever, or research on person walking around? It can help.

Designer
I think it is good to have a guide. Just like with a real escape room. Yeah, At the end of the day, the idea is to educate people about the project. So there also should be an educator on the topic.

Teacher educator
In that case, maybe what will be fun is like, what the STEM researcher said is let them do some research on their own as well. And for example, you can use the whiteboard, and that you can give them like a very broad question. And then they can like use one of these digital tools, they can kind of showcase what their answer is, or how they did research. And if there is an educator around, maybe the educator can then give points to the whiteboards. And that included in the code. Like if there is an educator, then let's make use of them, and maybe assign a few more tasks to it. But I think because I think it would be great. And I like the idea of STEM researcher to make them learn on their own as well.

Designer:
I think if we want to make it a bit like competitive and fun, it would be good. I know about its educational value, but maybe they can have a limited amount of hints from the educator. So they have they can ask the expert like five times, you know, that is also common in general escape rooms.

Teacher educator:
And do they can you also like measure time how long they are spending in this digital escape room?

Designer
It is not integrated into the program, but I think that the educator can do it themselves. Yeah.

Teacher educator
Because then you make it like competition within teams as well. Right? And then like for every instant they take they get one minute extra time or something like that. Yeah,

STEM researcher
that's great. Yeah. Okay, let's move on to the third.

Designer
Yes. To what extent does the module include activities to explicitly emphasize interdisciplinarity what other suggestions do you have to highlight this aspect? So interdisciplinarity

Designer
Well, I am not entirely sure because it is mostly about … I don't know. It is about wind energy and energy storage. So, it is mostly physics combined with a bit of chemistry I guess. Yeah. At the moment, I have not included environmental details about the project, but they can also be added to another room or the general entrance. Because the was a big part in the brochure that the battery could provide a safe space for ocean life to thrive.

Teacher educator
Interesting, very cool.
But I mean, like windmills are very disciplinary from their nature, right? So yeah, physics, but you automatically have math, you have biology, you have environmental sciences. So, all the topics that you have are actually in fact, interdisciplinary. Now, it's just a matter of highlighting each discipline within that, so I think it's, you're almost done. So, you just have to highlight a few things. You will maybe make a connection with social sciences as well. With a lot of topics that you discuss, people have impacts as well. Or, for example, we feel like how much energy can we … green energy cannot save us, or I don't know, like, I think that link is very easy to make and will be very appealing to

STEM researcher
Yeah, I agree with Teacher educator that there is a lot of similarities so far between science and mathematics, you have used some say also exercises that make them calculate stuff that have some scientific meaning. So, between science and mathematics, it's quite prominent. Also, through the simulation, we can, we can see that like technology helped us like to simulate the phenomenon, make decisions on the on producing things, what I would suggest is would be like in future iterations, that would be more explicit activities, to for the students to really reflect on the similarity. So, I mean, there should be some part or several activities or questions on reflecting on the similarities in order to make it more understandable for

children. And also engineering, as Teacher educator said, there is also several aspects, for example, through the simulation can also be discussed. Why should we put like windmills in the offshore? Why not in the hills? What pros and cons in, you know, by the environmental or social impact of them? And yeah, engineering can be integrated with other disciplines as well. But again, I suggest to be more explicit activities and questions about this, I think, right. Like to link it to the one of the ideas we have before. What I always like for interdisciplinarity, is take one topic. So, for example, now windmills and ask a question. And then just say to the students, how would a physicist answer this question? And now how would you as a person answer this question? And how would an animal look at this question, you know, and you automatically already get very cool, interesting, different answers? Which is all brought together by the topic that you use? Just an idea? That's good to understand different perspectives, and also how these cooperating in a project, maybe the animals that?

Teacher educator
Well, I mean, the biologists take into account the needs of animals, right? Yeah. Like with windmills? Actually, there are a lot of articles about this, that the windmills are very hurtful for birds, that there are a lot of dead birds because of we have windmills all of a sudden in place.

STEM researcher
We let's move on to the next one. All right.

Designer
To what extent does the module engage the participants in reflections as discussions about the impact of the relevant technologies on society? Well, not that much at the moment, because there is not a lot of discussion going on, apart from at the end, where there is a possibility to discuss a lot if they want to, but it is not yet implemented in the design.

Teacher educator
Yeah, I agree. It's also related to the first question, right, so the real world relevance. So yeah, this is something that has to be improved. But I don't think it's that difficult to implement.

Designer
I don't think it is difficult to implement, but I do think that the outcomes are pretty variable. So that would be a bit of a struggle to design rooms with just one password if the answers could be one group says this and the other group totally says something else. bit of difficulty, but

STEM researcher
I would suggest, I mean, just the potential I have never done it myself, but I will suggest like they can be rated on how many different dimensions can they realize, even though it's not their personal opinion, you know, if they can realize four different arguments, they get the higher rate somehow, you know, I don't know, I don't know how specifically this could be done. But that's an opportunity. Yeah, from my point of view, as Teacher educator said, it's, there are a lot of opportunities. It is there. It's not explicitly addressed so far, but it can be

more highlighted. And it can be also like in the beginning as well, but also as a reflection at the end. And also, in the simulation. There are some aspects that are very much connected with society, like, you know, this may increase efficiency, but on the other hand, it's worse for the public because for some people, it ruins the aesthetic of the places and stuff like this. There are many opportunities for sure. Yeah.

Designer
You could say that. Just let the students discuss a bit. And then the educator has a list of things he at least wants to hear. And then if he has heard all those points that that you didn't let them give the next code or something.

STEM researcher
Or for each argument, he the key again gives you a letter of code and then they can guess the words even though they don't have all the letters you

Designer
That would be the possibility.

STEM researcher
Okay, let's move on.

Designer
Next one, yes. So, what extent is the module include a reflexive discussion on conceptions of engineering thinking and engineering practices in general? Right? Yes. Quite a difficult one. As with all epistemological things, I'm not quite sure how to answer this.

Teacher educator
Do you have any ideas? These can be like parents or students?
Hey, we should start with Do you have an idea of what engineering thinking practices are?

Designer
Not really,

Teacher educator
okay. STEM researcher, do you?

STEM researcher
Yeah. There are several dimensions as I said before, it was like how, what an engineering does also what kind of constraints does he address like, we don't always want like to the maximum efficiency but also we have to consider like cost. We have to consider society, limitations by nature. Like, what is an engineer or like a career option like to let them students realize what an engineer and actually does and all the objects that he experienced in his life? How did they come and how engineering like really works? As with society, I think that there are a lot of opportunities, I would suggest, like some I don't know how to do that. We have any ideas maybe have like an expert in the game and trying to figure out like, he poses some questions about like, he's an engineer, pure engineer in the game, which can be

an educator, of course, and they can ask him what he can do and what he cannot do. I mean, all Maybe give them some other questions of Did you consider that? Or did you consider that? Or an engineer would not do that because of that because of time restrictions? Because of cost sections.

Designer
I did not consider all those things because,

STEM researcher
yeah, just thinking of some potentialities or have any ideas on how this can be addressed.

Designer
Not At the moment,

Teacher educator
you use Moore’s educational framework, right? For engineering.

Designer
Yeah.

Teacher educator
Yeah. Trying to look it up with all the different aspects.

STEM researcher
Yeah, this is one of the aspects like the students to understand what an engineering is, and what does he do? And the real context that an engineer works in, and what's different, and also, they have to understand that it's like an applied science, we don't think of something theoretically, but we are more focused on to do something that operates. Yeah, I think that one solution would be like to have like, a person in the in the game that they can ask, and he just criticizes them, like, okay, this is what you students do, but me and my job, I cannot do that because of that. So, he contradicts like what students really do with what a real engineering really does. And we will be happy because one of the educators is really into engineering. So maybe you can give some more good answers, I don't know.

Teacher educator
Like, so far, we talked about an educator, just giving some answers when you're stuck, right. So that's quite easy, anyone can do it as and then teacher doesn't need any additional time to prepare them because he just needs an answer sheet. But as soon as you give him or her they sorry, a task, as you just described, I think it would already require a lot more time from a teacher to prepare for this. And that will be a shame because the platform is amazing. Students can use this on by themselves, which makes it a very attractive and easy tool to use. So, if there is an other solution to do this, I would say do that. So, for example, you can just give them an engineering task, right? You can ask them to design something, and it doesn't have to do anything with the windmills, or you can, but like, think about a chair, and something that they know really well. And I think students are more than capable finding engineering. Problems about it like functionality versus costs, or in give them some

scenarios, like if you have a million dollars to design a chair, what will be the difference between a million dollar chair and a $10 Chair, for example, then students already automatically will be thinking about the design or the materials that they will use. What if you have one year to design a chair or 10 seconds? What if the chair has to be for one person or has to be able to hold 10 persons? Like I think these are all very intuitive for students? So, I don't think it's, you have to make it very difficult. And if you also get questions, I think, yeah, you have to think with a code. Right. So, I think that's the difficult parts. But I don't think you need an expert for students to be thinking to interact with engineer thinking.

STEM researcher
Yeah, just Yeah, I agree with this. But they should also have like a more explicit, maybe at the end of this more explicit question on think about what they do. So that's the difference. So, they experience the engineering practice, but they should reflect explicitly on this. So maybe at the end, there should be like a recap question of think of what you did, and what's different from what the science scientist would do. I mean, something signed consent. Yeah, I agree with this just to be a bit more explicit in the end. Do you have any other ideas? Designer?

Designer
No, I'm completely blank on this.

Teacher educator
Are you familiar designer with the engineering educational framework of Moore?

Designer
No, I don't think so.

Teacher educator
Okay, I haven't got it's interesting. To help you with this doesn't just work. I can send things in.

STEM researcher
Yeah, so it’s the one I send you in the slides. Yeah, but yeah, maybe you haven't been engaged with this. I think it's this one right. Yeah, yeah. It's the full article. This one Yeah. Yeah. Yeah, okay.

Designer
I'll have a look later today.

Teacher educator
Yeah, I think that will give you some ideas to approach this question, because it's a difficult question. Especially if you don't know the terminology, then of course it doesn't work. Yeah. So, this will help.

Designer

You. Final one. Final question is, to what extent does the module provides opportunities for collaboration and teamwork. I tried to implement that with use of the whiteboards because everyone is looking for the information and the hints and the questions around the rooms. I thought that they could collaborate a bit when trying to answer these questions by writing down all the information they found on the whiteboards and then solving the problems together. And for the question about the hydro dam. Yeah, I think they assign one person to head back one or two persons to head back to the video in order to find the answer. So, I have tried to implement a bit of collaboration. But as we pass through this, I think that that has still some potential for improvements.

Teacher educator

yeah, I think this is just a case of having a pilot study and figure out what students will do, I think this is very difficult to predict based on what you have so far, because I can imagine that if you are by yourself, because everything is quite close to each other in each room, right? So I think if you just run around like crazy person, all by yourself, you will still manage to do things. So maybe because the idea of one person sending back to the to the video that's a good idea. So but then you already have to have be able to access multiple rooms, which interferes with the codes. So yeah, I think this is just a typical case of finding out. Yes, yeah, maybe you know, with the suggestions that we already did, like doing the self learning activity by searching things on the web and maybe make some sort of mood board or something like that. That can already help.

STEM researcher

Yeah, at my point of view, I discovered something today actually, because we are three persons there are some let's say difficulties, but in a good way. So for example, you cannot watch the others camera and you cannot talk to the other if you are not close enough, it's a difficulty but at the same time, it's really good because it emulates like real world us like so if you're not like glow, it's part of restriction it's like a real world restriction as well, I mean, if you're not like close to him, you cannot collaborate the same level okay, you can still communicate. So, also you cannot like if there is some traffic like here you cannot like okay, you can use the ghost mode, but still, you cannot there is some for example, if you interact with an object, there are a couple of persons who are inside which are in front and you cannot, you know, get over them so, but I like these difficulties because it somehow it likes like real world situations. So,

Designer

it is basically what they now call the metaverse, it's all about immersion.

Teacher educator

Yeah, I like this. I like this fact, it was really good because it's good to have some difficulty so it's not like you know, zoom that everybody can like, you know, act the same. So, but I think that some things like the time factor time restriction, for example, if they have like this, to complete the task and like, if they do it in a shorter time, they get more points, it's it will make them collaborate more, they will assign roles. So, you can focus on this and then come back to me or then you can find this information and come back to me. So, like the time factor and the escape room factor can enforce them work some extent I imagine. And of course, if they are from different disciplines, I mean, they could also be good beneficial, like to get different types of knowledge and skills. Yeah, what else? I think that or no. It can also act like maybe if the groups between the groups, they can also like, chat or maybe they have some riddles for the other group as well. I don't know. I don't know. Do you consider that it's also applicable for like, several groups to play the game as well?

Designer
You mean...

Teacher educator
I mean, to have like two set of students doing this, you know,

Designer
alongside each other at the same time, or? Yeah, yeah. Well, for this program, you should design a complete second round to in order to do that. Yeah. And not be interchangeable. Inter communicable. Yeah.

STEM researcher
Okay, I think I think was a nice discussion. We want to delay more. Yeah. Do you have any final comments or something else to add Teacher educator?

Teacher educator
No, I'm very excited about this. I think it's very smart to do a digital escape room very appealing. And the platform looks great. Yeah, so compliments for that. And yeah, it was I think with the good, the questions we just discussed. You can like now; I think there's you can see it as a basis. And now you can revise it a bit more with the questions. We just discussed the implementing those things. But I think this platform is amazing. Yeah, very easy to use. Right. And I think that makes it a very attractive tool as well. Yeah.

STEM researcher
Yeah. For me, it's also like, it's fun. It's useful. It certainly has a lot of potentialities, we'll have to consider like in future iterations, how to do special diverse activities, you know, to also implement other stuff. Designer, do you have any final reflections?

Designer
Well, apart from that the program is indeed quite easy to use and attractive to see. It could be a bit buggy sometimes. So sometimes the doors don't work. You just get teleported to a completely different part of the room and then you're stuck. But that that's just the earth of the program

Appendix 2: Information hidden in the digital environment

For the hidden questions: see appendix 3

Entrance

Introductory text

Welcome to Ocean Grazer. You will soon learn about important aspects of the Ocean Grazer project in a fun and collaborative way. In 30 minutes, you need to solve puzzles in order to unlock every part of the project. The information you need to solve the puzzles is spread all over the map, so it is important to communicate well with each other. You can take notes on the whiteboards, and you are allowed to use a calculator if needed, but you are not allowed to use any search engines. Please proceed to the wind turbine room and watch the video carefully. Good luck!

Door to energy storing room

Let's store some energy!

Lately, the wind turbines have generated a lot of energy. Some of it needs to be stored to prevent destabilisation of the grid.

Door to energy usage room

We need more power!

There was almost no wind today, so we need some energy from the battery.

Door to final room

Congratulations!

You have successfully solved all puzzles. Please enter this room, so we can discuss what you have learned about Ocean Grazer.

Wind turbine room

- In 2020, there were 462 offshore wind turbines in the Netherlands (CBS, 2021).
- The total capacity of the offshore wind turbines in the Netherlands in 2020 was 2.460 MW (CBS, 2021).
- Assignment: Maximise the number of houses you can power in a year with your wind turbines and write down the amounts of Watts produced:
    - https://www.youngscientistlab.com/sites/default/files/interactives/wind-energy/
    - The wind turbine in the simulation was maxed out at 1255349 Watts

Energy storing room

- Each reservoir can hold up to 20.000 cubic metres of water (Ocean Grazer, 2022a).
- The Ocean Battery is highly modular. The storage system can consist of several connected, stand-alone units, allowing the system to grow along with the capacity of the wind farms by adding units as a wind farm expands (Ocean Grazer, 2022a).
- Each pump of the Ocean Battery is connected to a maximum of 4 rigid concrete reservoirs and 4 flexible bags (Ocean Grazer, 2022a).

- When water has been pumped to the bags, energy is stored as potential energy (Ocean Grazer, 2022a).

Energy usage room

- A general rule of thumb states that for every 10 m of water depth, the pressure increases by 1 bar (100.000 Pascal) (Van Rooij, 2012).
- To generate the 10 MWh, the bags need to be placed at a depth of approximately 45 metres (Ocean Grazer, 2022a).
- The water flows through large hydro turbines, which generate up to 10 MWh per system of four reservoirs and four flexible bags (Ocean Grazer, 2022a).
- The turbines have an efficiency of 70-80% (Ocean Grazer, 2022a)

Appendix 3: Hidden questions and answers

Wind turbine room:

Question 1: If all Dutch offshore wind turbines in 2020 produced as many Watts as your own maximized wind turbine, how many Watts would be produced in 2020?

- 462 turbines * 1255349 Watts = 579971238 Watts

Question 2: How many of your maximized wind turbines would be needed worldwide to reach the predicted 1150 GW of 2050?

- 1150000 MW / 1,255349 MW = 916081 Turbines

Code: Q1 / Q2 = 579971238 / 916081 = 633 → Energy storing room

Storing energy (filling bag)

Question: The mechanism of the Ocean Battery is based on the technology of what big structure? (Tip: The door hates the spacebar. Also keep track of capital letters)

- Answer: Hydro dam (if the participants don't remember this, they have to go back to the video in the previous room)

Code = answer → Energy usage room

Using stored energy (emptying bag)

Question 1: Let's say that the hydro turbines have an efficiency of 80%. How many MWh would be generated if the turbines were 100% efficient?

- Answer: 12,5 MWh (10 MWh = 80%)

Question 2: How high is the pressure in bar at the depth that is needed to generate 10 MWh?

- Answer 4,5 bar

Code: Q1 * Q2 * 100 = 12,5 * 4,5 * 100 = 5625 → leads to final room (discussion island)