What the Amazon Can't Deliver: Lessons Learned from Virtual Reality-Based Sustainability Education

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Abstract. With Virtual Reality technology becoming an increasingly popular method to convey knowledge, sound pedagogical principles are needed to implement Virtual Reality effectively in classrooms. This paper proposes a pedagogical model that provides guidelines for educational practitioners before, during, and after Virtual Reality instruction. For elucidation, concrete examples as well as generative learning tasks are provided. These are based on a Virtual Reality learning experience developed by *greenpeace* and its evaluation studies. Finally, some general strengths and weaknesses of the proposed model are discussed.

Keywords: Virtual Reality · Pedagogy · Instructional Guidelines

1 Introduction

Recently, a lot of effort is being put into empirical research on finding the most efficient way to integrate Virtual Reality (VR) technologies into the classroom. Such technologies appear promising for learning, especially in constructivist and interactive approaches [1–3]. However, meaningful instructional guidelines on how to integrate VR learning applications into the everyday classroom are missing. This article provides initial recommendations on how to effectively implement VR learning experiences into classrooms. Examples of learning activities, based on Wittrock's Theory of Generative Learning [4–6], and a comprehensive model for briefing and debriefing activities that accompany the virtual experience are provided. In general, the article tries to point out that a VR based learning experience alone is not sufficient to create a meaningful learning environment. It requires pedagogically valuable accompanying briefing and debriefing actions which subsequently need to be empirically validated.

2 Theoretical Background

2.1 Learning in VR

There are multiple theories that include a framework for learning with technologies that provide a high degree of vividness and sense of presence, called immersive technologies, like VR [7]. A major framework for learning with VR technology is the Cognitive

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Affective Model of Immersive Learning (CAMIL), wherein affective and cognitive factors like interest, motivation, or cognitive load mediate the effect of agency and presence on learning outcomes [8]. Agency is to be understood as a sense of control over one's own actions [8, 9], while presence refers to the feeling of actually "being there" in regards to a virtual environment [8]. Within this framework, presence, flow, and prior knowledge are relevant factors for gathering knowledge and perspective taking [10].

Similarly, Dengel and Mägdefrau [11] relate learning effects in virtual learning environments to the motivational, emotional, and cognitive potential of the learning situation, as well as to activities during learning. Their educational framework for immersive learning (EFiL) again cites the perception of presence as a relevant factor, but also considers instructional affordances, like the quality of the materials [11].

The meaningful immersive VR learning framework (MiVRL) stresses that providing meaningful learning opportunities is more important than creating high degrees of immersion [12]. Meaningful learning here refers to the generative process of using cognitive and motivational resources to actively connect prior knowledge with the to-be-learned material [5, 6]. Immersive learning environments should include segmented tasks that build on prior knowledge and practice constructive activities that are relevant to the targeted skill to foster knowledge transfer [12].

Common ground among the above models is found in the focus on cognitive factors. Indeed, immersive virtual environments seem to be related to higher cognitive load [13–15]. All models also stress the importance of presence and agency. This means that these factors should be considered when planning lessons around a VR application. Another relevant factor might be the experience of flow or perceiving an activity as satisfying and feeling as one with the activity [16]. Flow has a positive effect on learning and correlates with presence [17, 18].

With prior knowledge and agency as key factors, classes that rely on learning with immersive VR might have to find ways to relate that knowledge to the new information provided through interactive means. According to the Generative Model of Learning, perceptions and meanings are usually generated to be consistent with prior experiences [6]. This means that new information can be more easily related to prior knowledge and prior practical experience. The kind of task chosen should fit the to-be-learned material [5]. Fiorella and Mayer add that meaningful learning outcomes are enhanced with higher cognitive engagement, supporting higher degrees of constructive (inter-)activity over passive modes of learning [5]. They point out eight ways of designing generative tasks: summarizing (stating the main point of the learned material in own words), mapping (visualizing or organizing material in a map), drawing (depicting the contents of a lesson in a drawing), imagining (creating mental images of the learned material), self-testing (answering questions about the material), self-explaining (explaining the contents to oneself), teaching (explaining the contents to someone else), and enacting (engaging in task-related movements or object manipulation) [5].

2.2 Previous Findings

A multitude of studies have shown benefits of VR use in classrooms. The experience of flow and presence in VR might be beneficial for attitudes towards VR learning [19] and learner satisfaction [10]. Setyowati et al. [20] were able to increase participation via VR instructional media. Another study found positive effects of VR for learning car detailing, a procedural learning task [21]. Hence, presence and flow seem to be the main factors that influence learning outcomes in VR [10, 19].

However, Hamilton et al. [22] note that while many studies find immersive VR advantageous, oftentimes only short interventions with inadequate methods of measuring learning outcomes are implemented. Only rarely are long-term effects of VR-based interventions investigated [23]. This is tied to another flaw within many research designs: the lack of consideration for greater curricula. Mulders et al. [12] argue that VR-based interventions can only be effective if they are part of a lesson plan, not just novelty gadgets. Indeed, designing virtual learning environments to fit cognitive, affective, and motivational needs is only one aspect of suitable VR-learning. In the formal classroom setting, pedagogical and instructional implications should be considered for effective implementation [24].

First, students' prior knowledge should be addressed before its usage, as this is required to gauge the level of content detail and scaffolding that should be provided. Additionally, constructive learning activities before as well as after the virtual experience should be included to fully exhaust the interactive, high-agency nature of VR technology [4, 12]. Generative learnings tasks seem to positively affect transfer, retention, and motivational factors [4, 25, 26]. Moreover, immersive VR works in part through the mechanism of presence [8], which is also linked to better generative task performance [25].

2.3 Briefing and Debriefing a VR Learning Experience

The synthesis of the models for immersive VR [8, 11, 12] as well as generative learning strategies [4–6] can result in practical recommendations for teachers and schools on how VR technologies can be used to enhance learning in classrooms. It is advisable to differentiate between before, during, and after the virtual learning experience. On a theoretical level, we introduce a model here (see Fig. 1), which will be filled with exemplary content in the next step using a specific virtual learning application by *greenpeace.*

For the briefing of students, the above frameworks suggest that prior knowledge should be activated [8, 11, 12]. This includes ensuring that all students have a somewhat similar basis of knowledge before going into the VR intervention. Therefore, background information about the topic at hand should be provided in a short opening prompt that is engaging enough to also capture the students' interest [27]. A more basic prerequisite for working with VR applications is a sufficient number of devices as well as students' technical knowledge on how to operate those. Teachers should ensure that students understand how their devices work, so that the learning experience is not impaired by technical difficulties [28], which in turn might be detrimental for cognitive load [29]. Before the virtual learning experience starts, students should also be reminded that the virtual world they are about to encounter is different from the real world [30].

During the virtual experience, teachers should be ready to assist students if they have any questions, be it technical or content-related. Additionally, background noise or other distractions or interferences with the virtual experience should be avoided. Also, providing helpful information just in time in VR or breaking down a complex VR into smaller segments can prevent overload.

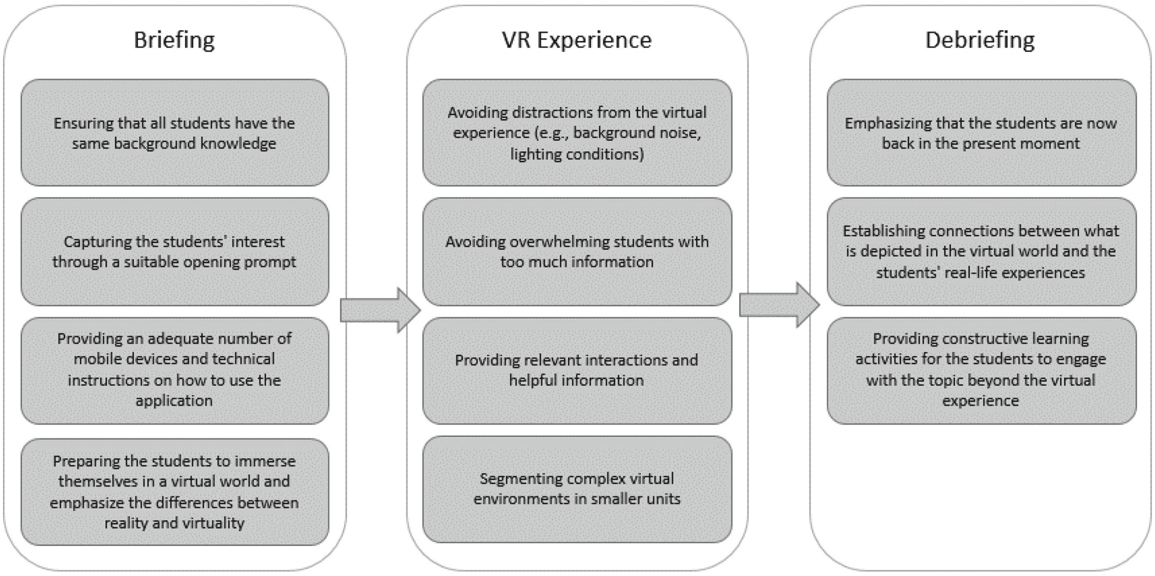

Fig. 1. Pedagogical model for working with VR. The model lays out tasks for teachers before, during, and after use of a VR application.

To start the debriefing phase, teachers may emphasize that students have left the virtual world and are now back in the present moment [30, 31]. Next, a link between the information gathered in the virtual experience, students' prior knowledge, and their real-life experiences should be established. This can be enhanced by providing constructive learning activities that encourage students to engage with the topic beyond the virtual experience [4].

Using an app from *greenpeace*, the model will be filled in the following with specific recommendations that accompany the use of the app before, during, and after. For this purpose, a short overview of the findings of its evaluation project will be given next.

3 The *Greenpeace* Project

In one recent study, we [32] have investigated the aforementioned application. It allows students to virtually visit four locations that would be difficult to experience first-hand in a regular classroom setting. This includes specific landmarks like the Amazon rainforest and the Great Barrier Reef (see Fig. 2), as well as more general settings, like a German forest before and after soil sealing. Here, they can explore their surroundings, interact with avatars resembling residents, and gather information on the environmental impact that human actions have had there. The Amazon rainforest setting deals with deforestation for meat production and its impact on the Brazilian indigenous population and local wildlife. The Great Barrier Reef setting focusses on the rise in water temperature and its effect on the flora and fauna underwater. The German forest setting deals with soil sealing and the dispersal of local birds through unsustainable agricultural use, while the supermarket setting illuminates global supply chains in food production.

This application in particular is interesting because *greenpeace* provided an elaborate manual specifying the prerequisites and thematical framework for a lesson in which their app could be introduced [33]. This includes pedagogical impulses on the 17 Sustainable Development Goals [34] and possible discussion threads (i.e., *"What are possible solutions for the challenges you encountered?"*; [33], p. 11).

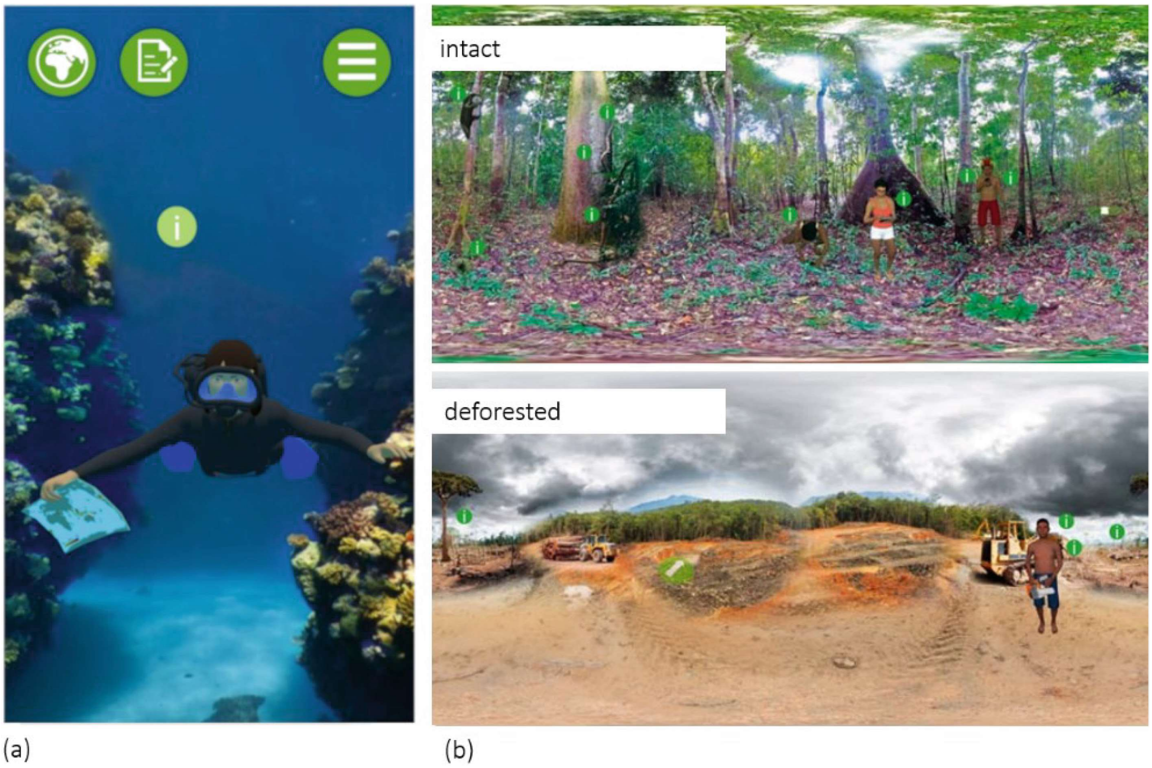

Fig. 2. Screenshots of the *greenpeace* application. (a) shows an underwater scape at the Great Barrier Reef. (b) shows intact and deforested versions of the Amazon rainforest.

Detailed evaluation results can be found in [32, 35, 36]. The first of those papers focuses more heavily on the quantitative portions of the utilized mixed-methods approach, where 172 students from eight German secondary schools filled in questionnaires on self-assessed knowledge, interest and attitudes after either a lesson with the *greenpeace* application or a traditional lesson. In short, change in self-assessed knowledge and attitude was achieved when using the app, yielding small effects (Cohen's d between 0.34 and 0.42). However, this was highly dependent on school form, with academic track students seemingly having an easier time learning with the app whereas students in vocationally oriented schools performed better in the control condition [32]. The second paper looked more thoroughly at possible moderators within the experimental condition. For self-assessed knowledge, the analysis indicated that flow and presence were moderators of the difference between pre- and posttest scores [35]. Especially students with little prior knowledge benefited from experiencing flow and presence. The analysis also revealed a high correlation between flow and presence ($r = .58$), as well as significant correlations between flow and self-assessed knowledge, interest, and two out of three attitude measures [35]. The third paper presents results of eight focus group interviews that 84 of the experimental group students (between 2 and 25 per school) volunteered for, and is more focused on the qualitative portions [36]. A content analysis [37] of those follow-up focus group interviews showed that students mentioning a change in attitude or behavior was often related to them talking about their feeling of presence during the lesson [36]. This corroborates the quantitative findings and supports the role of presence for learning in virtual environments, as hypothesized by the theoretical frameworks [8, 11, 12].

Curiously, there has been a discrepancy in statements by teachers and students. While teachers seemed critical of the high information density provided by the application and pointed out that some students had difficulties with selecting relevant information, many students stated that they found the amount of information beneficial for their learning experience. In total, students rated the app-based lesson on average a 7.5 out of 10 ($N = 62$), indicating a favorable rating [36].

Teachers and students agreed that they would like to see more and similar applications for other school subjects. According to one teacher, a virtual environment might lend itself to visualizing abstract scientific concepts that would otherwise be difficult to grasp, like electricity or molecular forces. Students seemed more interested in the world travelling aspects, which could support more immersive language learning. Students and teachers also agreed in their wish for a higher degree of interactivity. They proposed a more gamified version, where the application gives learners additional tasks to complete [36].

Generally, while students seemed very enthusiastic about VR use in the classroom, teachers were more skeptical. Especially for attitudinal and behavioral change, teachers remarked that the application might not give students enough time to reflect on the new information and could be more relatable, e.g., by addressing products students more commonly use, instead of tropical wood or nuts. Teachers did, however, seem content with using apps like the present one again in their classes. One teacher expressed that their students enjoyed the lesson a lot, even seemed surprised by the technical capabilities of their phones, and that making learning fun carries inherent value.

Based on our findings of the *greenpeace* project, the following section aims to explore requirements and ramifications for curriculum-oriented VR use in classrooms, what these kinds of applications can and cannot achieve, all while considering both teachers' and learners' perspectives.

4 Pedagogical Implications

4.1 What the App Can Do

Working with the *greenpeace* application offered an opportunity to apply concrete pedagogical procedures to the previously laid out model (see Fig. 1). In the recent study of Mulders et al. [32], the application was designed in a way that does not require preparatory steps, like downloading any data or sharing private information, but only a stable internet connection. The briefing section implemented in the study by Mulders et al. [32], started with a prompt on the 17 Sustainable Development Goals [34]. This could, for example, come in the form of a short explanatory video, as they are often found on video platforms like YouTube. A hypothetical question like "*In which ways would you like to design the 21st century?*" [33] could allow teachers to segue to SDGs, if students bring up tasks that are adjacent to those. Another possible learning activity might be a multiple-choice test with subsequent resolution as an option to bring students onto a similar level of background knowledge [8, 11, 12]. A key or legend explaining symbols that will be encountered in the intervention should also be provided, if necessary, to avoid confusion [9, 26, 27]. For example, the *i*-symbol is frequently used to indicate that more information is available. Tapping an icon with an *i* on it might lead to students finding additional information on whichever item they are currently examining within the VR application.

During the intervention in the study of Mulders et al. [32], teachers were mainly concerned with answering arising questions, helping with technical difficulties, and making sure that distractions were kept to a minimum, for example by asking students who had already finished the virtual exploration to remain quiet while others were still working. The *greenpeace* app, in its current version, is already designed to avoid overloading students and is divided into four different segments (here: habitats), allowing for various interactions. Only the simultaneous presentation of spoken and written text should be avoided in future versions in line with the modality effect [38].

In the study of Mulders et al. [32], the debriefing opened with welcoming students back to reality and continued with a quiz. This was followed by a reflective discussion in class, where thoughts, emotions, or specific parts of the exploration that made an impression on the students could be addressed. While the quiz is a self-testing generative task and mainly based on retrieval-based learning, the discussion incorporates parts of the summarizing and self-explaining techniques, in that the ideas conveyed through the application need to be stated in one's own words and made sense of to be able to discuss them with others [5]. Teaching, or explaining to other students what they have just learned, was not investigated within the study of Mulders et al. [32] but would also be a suitable generative learning task. For example, instead of having all students select the same learning habitat in the presently used application, teachers could split the class into groups. Those could in turn explain the different learning experiences in the different habitats to each other [5].

Following up on the lesson, additional learning experiences could be mapped out as mentioned in the focus groups. Examples include a homework assignment or class field trip to find out about products in local supermarkets that use components produced in the Amazon rainforest. For example, students could be split into groups to find a specific number of products from different aisles and check them for ingredients that might originate from the Amazon, or compare their prices with products that are more sustainably produced. This might make the experience more relatable to the real-life environment of students, as suggested by some teachers in the focus group. These practical examples for the model are summarized in Fig. 3.

Overall, pedagogical conclusions can be drawn. VR applications can positively affect knowledge in students [10]. While the quantitative knowledge measures of the *greenpeace* project can be criticized, students in the delayed focus groups were still able to recall large parts of the information they received during the VR class, meaning some degree of retention took place [35]. Still, this means that VR applications for classroom use should come with a plan on how to thematically lead up to the VR intervention to activate prior knowledge, and how to debrief the students afterwards. The *greenpeace* manual offered guiding questions for group discussions [33], however other kinds of

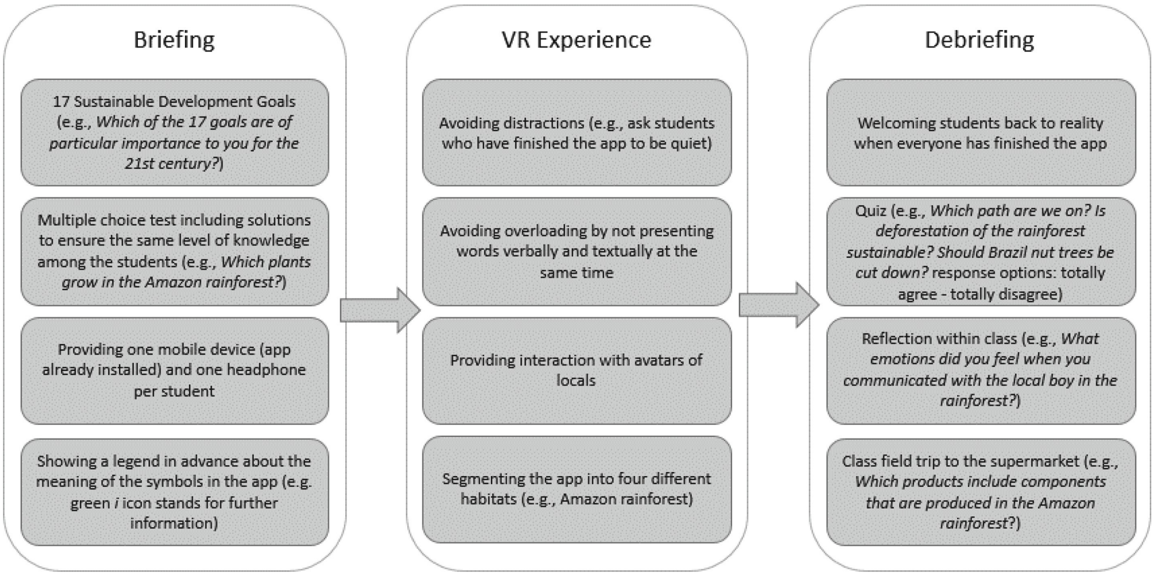

Fig. 3. Example tasks for the pedagogical model for working with VR. The examples are specific for sustainability education via the *greenpeace* application.

activities are desirable, like generative learning tasks to foster meaningful learning and higher engagement [5].

Students reported they had discussed general issues in the Amazon rainforest with peers and parents [36]. On one hand, this implies that learning in VR could be a useful starting point for teaching topics that lend themselves to open discussions, like social sciences. On the other hand, this also shows that VR-based lessons need to be planned with enough time for students to reflect on their experiences, as noted by some of the teachers.

For behavioral consequences from those attitudinal changes [39], statements from the focus groups were mixed. Students seemed at least somewhat eager to change their behavior, e.g., by buying fewer products that require palm oil. However, whether those ideas develop into long term behavior or even inspire more environmentally friendly actions remains unclear. As expressed above, teachers were critical as to whether this sort of intervention would at all be able to induce long term changes in behavior.

The overall benefits of this sort of intervention seem to lie partly in its novelty for students, but also in the ability of VR to make distant, abstract, or otherwise difficult to grasp topics palpable through perceived presence [8, 10, 11, 17–19]. In contrast, limitations and implications of what this setup cannot do will be discussed in the following chapter.

4.2 What the App Can't Do

No single method, application, or technology can be a miracle cure for all pedagogical ailments. Within the *greenpeace* project, teachers reported that they found their students to be more fatigued after the VR lesson than they were after conventional lessons, implying VR interventions should be kept short and only make up a part of a class, not its entire runtime. Naturally, because VR applications often require learners to move around, they put a higher physical strain on students than common sedentary classes. This kind of strain should generally be kept in mind when integrating VR-based technology into curricula. Developers could, however, incorporate a mix of tasks with differing levels of physical strain into their VR applications.

It has to be kept in mind that VR in education is supposed to be a supporting tool and cannot replace instruction. Teachers as well as students in our focus groups agreed that a blend of VR-enhanced and (what they considered) conventional classes would be optimal. It should also be kept in mind that a fit between the method and the to be learned knowledge should be created. For example, teaching procedural tasks might benefit more from the interactive qualities of VR-based instruction than teaching declarative knowledge [21].

One point of uncertainty that remains is the quantity of information provided. While students asked for a more open world to explore, teachers were skeptical of the information density and stated that the *greenpeace* application could be narrower regarding the number of topics, but more in-depth. From a cognitive load perspective, apps that provide more concise information would likely be beneficial [14, 27], however, from a developer standpoint, creating a singular, more encompassing application might seem more economically viable. A solution could be to give teachers the opportunity to lock and unlock specific parts of content. This could also play into a more gamified approach [3, 19, 40].

With *artificial intelligence* (*AI*) showing the potential to be an increasingly viable tool in application and game development [41, 42], future VR applications for classroom use might be able to utilize procedurally generated surroundings that are adapting to the learner. A higher degree of interactivity as requested by some students [36] could possibly be achieved with the help of large language models [43–45], for example by pairing the representation of a resident or expert avatar with a chatbot who can answer questions or accompany the learning experience [46, 47]. This would also lead to a more unique learning environment for each student, which could in turn encourage a more extensive exchange between students, since every one of them would have had a slightly different experience with the application.

Finally, some prerequisites should be addressed. Students with little prior experience in VR might struggle with VR-based instruction [32, 48], although research results are mixed [49]. This implies that efforts of VR-based instruction might be futile without at least a certain degree of media literacy or technological savviness [50]. Applications like the *greenpeace* VR experience might also not be able to uphold the air of novelty the more popular VR becomes. There is possibly a conflict between the benefits of prior experience with VR technology and the engagement provided by the novelty effect [51], as well as a possible link between lack of prior experience with VR and change of real-life behavior, making attitudinal and behavioral change less likely the more experienced the user becomes [52].

5 Conclusion

In the present paper, we provided a model for VR-based teaching that is sub-sectioned into three parts: before, during, and after the VR experience. For each section, pedagogically sensible generative activities as well as general recommended actions for instructors are included. This model was developed with the *greenpeace* application in mind. However, teachers as well as researchers should easily be able to adapt, adjust, and expand this by no means complete model for their own needs and applications. We hope that this model will be able to help popularize the integration of VR technology in classrooms, not for its own sake, but for the sake of pedagogically sound instruction that fits the learning task.

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