European Journal of Geography

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Received: 15/04/2024
Revised: 08/06/2024
Revised: 27/06/2024
Accepted: 30/06/2024
Published: 02/07/2024

Academic Editor:
Dr. Alexandros Bartzokas-Tsiompras

DOI: 10.48088/ejg.p.ben.15.2.120.134
ISSN: 1792-1341

Research Article

Promoting technological literacy through virtual game-based field trips: Effects on knowledge, attitudes, and gender

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Abstract: Virtual field trips in combination with digital game-based learning offer great potential for creating new learning environments, especially for geography education. Those approaches are not only needed to transfer knowledge but also to con-tribute to creating a more technologically literate society. For the future design of learning spaces and the corresponding professional development of teachers, it is indispensable to learn what the pedagogical advantages and limitations of fully virtual game-based approaches are. For this, it is necessary to know whether purely virtual concepts differ in knowledge transfer from those applied in technology-supported field trips on site. When it comes to promoting technological literacy, additional relevant questions are whether there are influences on participants' attitudes toward modern technologies and whether there are implied gender effects in this regard. An empirical comparative study of a total of n=110 German high school students was conducted using a survey to answer these questions. Key results are that actual and virtual designs using technology-supported game-based learning approaches can be equally effective in knowledge transfer. Further certain technology-averse attitudes could be identified, which were more prevalent among females than males. This gender gap could be leveled out by the effects of the virtual game-based field trip. Across genders, the levels of aversion were reduced, as well, while affirmative attitudes toward modern technology rose.

Keywords: Virtual Field Trips, game-based learning, gender studies, technological literacy, forest ecosystem, geography education

Highlights:

- Combined DGBL-VFT approach effectively conveys subject-specific knowledge.
- VFT fosters technological literacy via participants' tech attitudes.
- Gender gap closed by strong positive effects on females' attitudes.

1. Introduction

Society is witnessing a self-accelerating technological shift impacting all areas of human development. As geographical education is not unaffected by this, this study aims to offer a unique perspective on the integration of digital media in this field, which has been little studied to date. The technological shift, perceived differently by individuals due to varying digital accessibility and personal inequalities (Francis et al., 2019; Nueva, 2019), poses both opportunities and challenges. Modern technology has the potential to either solve or exacerbate global ecological, economic, and social issues, depending on its application. Philosophical models, like those proposed by Verbeek (2024), position technology within a multi-dimensional human-technology-environment relationship, acknowledging both its social construct and deterministic characteristics (Latour, 2021). The COVID-19 pandemic accelerated the transition of many interactions to the virtual world, significantly affecting how young people perceive and interact with their environment (Allert & Richter, 2017). Digital media, including games and mobile applications, play a crucial role in this shift. However, uncontrolled use of technology can lead to adverse psychological outcomes (Oswald et al., 2020). Thus, fostering technological literacy is essential to empower individuals to actively use technologies beneficially, rather than becoming passive consumers (Dyrenfurth & Kozak, 1991).

The International Technology and Engineering Educators Association (ITEEA) states that technological literacy involves understanding technology, its workings, and its societal impacts, as well as developing awareness of its potential negative consequences (Buelin, et al., 2019). Issues such as alienation from nature due to excessive digital media use (Edwards & Larson, 2020), gambling addiction (Liang et al., 2022), and sleep disorders (Wood et al., 2013) highlight the importance of educating young people about technology's impacts. Scholars like Ardies et al. (2013) suggest that positive attitudes toward technology can enhance technological literacy.

Despite the stereotype that males have a more positive attitude toward technology than females (Cai et al., 2017; Niiranen, 2016), re-search on gender differences in this field remains inconclusive (Islahi & Nasrin, 2019; Svenningsson et al., 2022). Addressing these attitudes and inequalities requires concrete educational approaches (Huff et al., 2012). Geography education, in particular, offers significant potential for integrating technology through field exercises and mobile applications (Firomumwe, 2021).

Technological advancements have enabled the creation of new learning environments, such as virtual field trips (VFTs), which can effectively communicate complex contents and increase competences as they appear in many topics of modern geography education (Edwards & Larson, 2020; Ho et al., 2022; Roelofsen & Carter-White, 2022). VFTs are able to provide multimedia content and interactive features, like story-telling and augmented reality, enhancing comprehension and engagement (Camacho-Sánchez et al., 2022). Many educators for geography might already know game-based learning as a quite prominent feature, offering interactive models of real or fictional realities that support learning by simplifying complex information (Prensky, 2003; Rogelj et al., 2024). Studies indicate that adolescents particularly prefer playful elements in educational applications (Cesário & Nisi, 2022). Successful implementations of digital game-based learning in geography include both actual interactive field trips and virtual learning experiences (Giannakas et al., 2018; Ho et al., 2022; Huizenga et al., 2009).

VFTs are gaining popularity in education due to their ability to provide immersive learning experiences, accessible without the logistical challenges of actual field trips (AFTs) (Bruch et al., 2011; Klippel et al., 2019). They offer significant benefits, including reduced costs, lower ecological impact, and improved accessibility for students with disabilities (Klippel et al., 2019). Moreover, VFTs' novelty and adaptability to educational needs make them particularly appealing to young learners (Çaliskan, 2011; Salsabila et al., 2022).

Despite the extensive research on VFTs and DGBL, studies combining these concepts are scarce (Alsaqqaf, 2022). This gap highlights the need for further investigation into how interactive DGBL features in VFTs can enhance the understanding of complex geographical topics and promote technological literacy. This study aims to address this gap by exploring the effectiveness of VFTs integrated with DGBL elements in fostering knowledge acquisition and positive attitudes toward technology.

2. Literature Review

In the present study, we are particularly interested in the application of interactive DGBL features in VFTs and their effects on the acquisition of subject-specific knowledge, compared to AFTs with similar features. Further, possible effects of a game-based VFT on participants' attitudes toward technology and, thus, on their technological literacy will be investigated.

The independent attainment of the status of a technically literate person who can confidently navigate actual and virtual technology-based contexts is often hindered by several factors. Certainly, some people are content with their status as passive users and show no further interest in gaining more insight into, understanding of, and control over such technology (Gram-Hanssen, 2008). Others are skeptics with rational apprehensions that appear partly justified by potential negative impacts on the people or environment resulting from the abuse or disproportionate use of modern technology (Welledits et al., 2020). Some, however, are influenced by attitudinal barriers, such as irrational fears and aversions, which might be based on a lack of knowledge and the distorted image of modern technology that prevails in society (Khasawneh, 2023). These favor the perceived loss of control of the skeptics or their feelings of being overwhelmed by the complexity and intimidated when dealing with new technologies. With the promotion of technological literacy as a higher goal, several influencing factors have to be taken into consideration. The ITEEA, for instance, identifies knowledge and skills in terms of how to use, manage, and understand the crucial benefits and risks of current and future technology (Buelin, et al. 2019). Ardies et al. (2013) also state that the attitudinal dimensions related to technology correlate with a person's technological literacy. Consequently, we are dealing here with an interplay of knowledge, practical skills, or behaviors, and content-related attitudes. The influence of knowledge on a person's attitude is just as well-known in psychology, as both knowledge (e.g., conceptual knowledge and subject-specific knowledge) and attitude influence a person's behavior (Eagly & Chaiken, 2011). From this basis, it can be concluded that for an educational process that is intended to contribute to technological literacy, effective knowledge transfer is the cornerstone on which attitudinal changes and behavioral adjustments can be built and ultimately empower effective, conscious technology-related actions (Ardies et al., 2013; Nikolaou et al., 2022).

2.1 Knowledge Acquisition

"In changing situations of knowledge acquisition and use, the new interactive technologies redefine – in ways not yet determined – […] what it means to become *literate* or an *educated citizen*". (Lave & Wenger-Trayner, 2011, p. 12)

Effectiveness in the sense of the knowledge acquisition of both mobile and digital learning approaches for field trips (García de la Vega, 2022), as well as for DGBL approaches (Camacho-Sánchez et al., 2022; Wang et al., 2023) has already been demonstrated in various areas of actual extracurricular education (e.g. Knoblich, 2020). Still, when it comes to the educational qualities of VFTs, opinions vary.

With reference to education for sustainable development (ESD), Siegmund et al. (2013) argue that the importance of an original occurrence in a real situation cannot be simulated or even replaced by a virtual representation. The scholars emphasize that preeminently on a sensual level, being in a virtual forest landscape and experiencing a forest "live" are fundamentally different. On the other hand, however, a number of studies already exist especially several recent ones, that attest to the use of VFTs as an effective didactic tool. Cheng and Tsai (2019) for instance, report enhanced students' motivation in VFTs and highlight the important role of experienced realism and perceived spatial presence. Salsabila et al. (2022) even provide evidence that the spatial intelligence of participants is significantly influenced by VFT and improves their problem-solving abilities. And then there are growing numbers of studies, which present evidence of improved knowledge, changed attitudes, and influenced awareness through VFT participation (Al-Mugheed et al., 2022; Robledo & Prudente, 2022). However, the number of studies that directly compare VFTs with AFTs is rather small. The researches of Stumpf et al. (2008) and Ruberto et al. (2017) attest VFTs' and AFTs' equal effectiveness, while Klippel et al. (2019; 2020), Zhao et al. (2020), and Firomumwe (2021) report clear advantages of VFTs compared to AFTs in both geoscience and geographic educational frameworks. Some findings even provide evidence that effective VFTs are not necessarily limited to immersive setups, such as head-mounted devices, but can also make use of simpler technological solutions, such as desktop VR (Zhao et al., 2020). Even though creators of both AFTs and VFTs often make use of technological features and gaming elements to catch and hold participants' attention and to motivate and support the acquisition of knowledge (Alsaqqaf, 2022; Huizenga et al., 2009), no comparative studies can be found in which these DGBL components have been explicitly considered.

2.2 VFTs and DGBL

DGBL, however, offers great pedagogical potential for actual and virtual settings. Thus, their significance for geography education in specific, seems to increase further, as a current study by Morawski and Wolff-Seidel (2023) emphasizes. Almost two decades ago, Virvou et al. (2005) provided the first evidence, that games help to improve and retain learners' knowledge, by comparing a VR game for primary school geography students to educational software lacking the gaming aspect. Others followed as summarized in Merchant et al.'s (2014) meta-study on the effectiveness of VR-based instruction. Their results confirm that gaming elements in simulations or virtual worlds show higher learning gains. A different example is the work of Ho et al. (2022), which compared virtual and non-virtual versions of one and the same board game to improve students' knowledge of and attitudes toward sustainable development, and even though both approaches were successful, the digital variant performed better in both areas. Next to better knowledge gain and higher motivation, current studies also suggest that game-based VR interventions can have significant effects on content-related attitudes (Agbo et al., 2022).

Supporting arguments for technology in the form of mobile applications, digital games, and VR as part of modern education are sufficiently available. As their use and design possibilities rapidly evolve in both actual and virtual settings, the question, of which setting the pedagogical value is actually higher, will increasingly be asked in the future. The urgent relevance of this question arises from mundane factors such as organization, effort, and costs. But on the other hand, it also has profound implications for the future development of teachers' competencies or the infrastructure and equipment situation in schools. Only with a direct empirical comparison could clear statements be made about the advantages and disadvantages of the use of one or the other variant. Since most pedagogical approaches focus on imparting subject-specific knowledge, their success should also be the determining parameter in a corresponding comparison. Despite all the upcoming research in this area, to the best of our knowledge, to date, no studies exist that specifically compare the effectiveness in terms of knowledge transfer of an AFT and a VFT containing an identical DGBL approach. One reason why this type of comparative study still does not exist may be because of the challenge of comparing two rather complex but still identical concepts in disparate settings. For reasons of good empirical practice, the comparability of the two variants must be assumed in any case. Only when the central parameters provided, such as the group of subjects as well as the intervention's content, structure, methods, and media used, are approximately the same in both variants is a sensible comparison possible (Bühner, 2011). In our study, we want to create the named conditions for such an approach and, thus, answer the following research question:

- RQ 1: How does a game-based VFT compare to its actual physically implemented counterpart when it comes to imparting subject-specific knowledge?

2.3 Attitudinal Change

Since education generally pursues more goals than the mere transfer of knowledge, it seems worthwhile to also consider potential effects of DGBL and VFT on other pedagogical dimensions. There are for instance recent studies that show, that the use of modern educational technologies can positively impact the learner's enjoyment and perceived ease of use (Cárdenas-Sainz et al., 2022). Further, Robledo and Prudente (2022), conducted a VFT study with senior high school students in Manila and found significant effects on their environmental awareness and changes in their environmental attitudes. A literature review on this topic revealed that most scholars examined positive effects of educational VR interventions on attitudinal factors, such as emotions and empathy (Pirker & Dengel, 2021). Meanwhile, there is also increasing evidence in this area for the positive effects of combined approaches of VR and DGBL. In addition to studies that focus on attitudes toward the didactic concept itself (Araujo-Junior & Bodzin, 2022), there are also studies that examine changes in the attitudes related to the actual content. Reference has already been made to the study by Ho et al. (2022), in which the use of a virtual game approach showed an impact not only on the subjects' knowledge about but also on their attitudes toward sustainable development issues. Another example is the work of Agbo et al. (2022), in which attitudes toward computational thinking concepts were increased with the help of a VR game-based app.

Gender differences in content-related attitudes are a much-debated issue. Although not widely discussed, it is an important topic, for game-based virtual interventions in relation to attitudes towards technology.

2.4 Gender Differences

Recent studies show that females are attributed a different approach to gaming than males, who are predominantly associated with the field (Kelly et al., 2023). In contrast, results show that females learn more and are more motivated on field trips than males (Bätz et al., 2010). When it comes to the technology-related differences in attitudes between females and males, controversial studies have constantly been presented in recent decades. Well-known, old-fashioned stereotypes of tech-savvy boys and tech-shy girls are often underpinned (e.g. Marth & Bogner, 2019) or attacked (e.g. Svenningsson et al., 2022) by the respective publications. This makes it clear that the gender aspect has a certain relevance when it comes to promoting a technological literacy, which should take place for all members of our society, regardless of gender (Perez Sedeño, 2021). However, in the meantime, two things seem to have become clear, at least, which shows that the problem is more complex than initially thought: First, in most studies, several features in addition to gender have contributed to the variation in effect sizes. This seems obvious if you think about the variety of study designs and requirements of different target groups. Second, in particular, a more recent study from Svenningson et al. (2022), but also the meta-analysis of 50 articles from the past two decades by Cai et al. (2017), clearly shows that gender differences, if they appear, are expressed differently in distinguishable psychometric dimensions. Here, the cognitive, affective, and behavioral attitude dimensions are mentioned more frequently (Huff et al., 2012).

Recent studies by Bengel and Peter show a clear gender difference in the affective dimension, both among university students (2021) and adolescents in high school from the 9th to 12th grades (2022). This is explicitly represented by perceived intimidation, where significantly higher scores were observed for female respondents in both cases. Since there is evidence that students' technophobia impacts their technological acceptance (Khasawneh, 2023), a reduction in perceived intimidation is of the essence if closing the gender gap and promoting technological acceptance and literacy are the goals. To do so, the authors recommended deliberately addressing this affective dimension in concepts of technological education. Svenningson et al. (2022) name interest as another representative of the affective attitude and also describe this dimension as one of the most important influencing factors and as significantly related to the other two components. Among females, a strong relationship between cognitive and behavioral levels is also reported. Thus, the authors' recommendations for technology education are aimed at stimulating interest through engaging tasks, on the one hand, and conveying a broader conception of technology to females in particular, on the other.

Given that the above-mentioned findings and recommendations can successfully be implemented in a game-based VFT concept, it is essential to observe the latter's possible effects on technology-related attitudes and even examine potential contributions to the reduction of the much-described gender gap. This brings us to the following three research questions to also be answered by this study:

- RQ 2 Are there significant effects on content-related attitudes as a result of participating in the game-based VFT?
- RQ 3.1 Are there significant gender differences in technology-related attitudes among observed participants?
- RQ 3.2 And if so, do these change as a result of participation in the game-based VFT?

3. Methods

3.1 Concept Description

The SENSO-Trail (Science Education and Natural System Observation) is an extracurricular educational program for secondary school students funded by the Hessian State Ministry for Higher Education, Research, and the Arts, Germany, and it was developed as part of the LOEWE priority project Natur4.0—Sensing Biodiversity (Zeuss et al., 2023). It applies modern technologies and digital media to teach subject-specific knowledge and scientific methods of innovative environmental monitoring in geography education. This happens interactively and through using games based on authentic examples of actual research in German forest ecosystems.

The concept has been implemented through two variants. The first is an actual physical adventure trail in the research and teaching forest of the Philipps-University Marburg (Figure 1).

Participation is mainly self-controlled and coordinated by using the associated app on a mobile device. Second, the SENSO-Trail360 is designed as a purely virtual fieldtrip that can be visited and experienced indoors regardless of one's location. It is accessible on a desktop computer as a modular tour through the simulated forest, consisting of 17 high-resolution 360° images with the app as the central control unit.

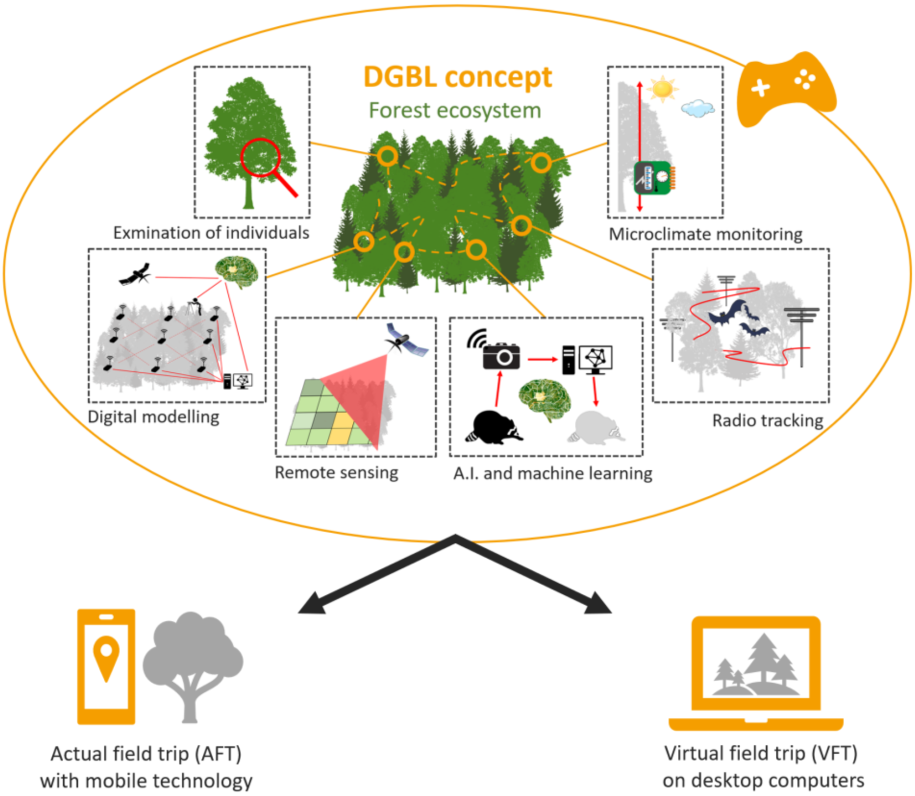

Figure 1. Two variants (actual and virtual) implementing an identical DGBL-based field trip concept

The content and structure of both concepts are identical and consist of several stations (information transfer), examination points (interaction), and quizzes (knowledge feedback and retention) on different ecological, geographical, and technological sub-topics. Central media for information transfer, coordination, and instruction are auditory and visual sequences (voice messages, images, and animations), which are made available via the app, along with a personal research portfolio with a scoreboard and an interactive digital map of the area with additional informative features.

Successful participation results in an understanding of the complex biotic and abiotic environments and their mutual spatiotemporal relationships, together with an awareness of scientific procedures for the examination of the underlying complex causal structures. Additionally, modern technology is promoted as a key element, both to obtain relevant information (for example, environmental data through sensors and measuring stations in the forest) and to better understand this information (through the didactic elements of the educational application). Together a picture of the synergic effects of a human-technology-environment relation triangle is drawn and used to identify and discuss the potential of its current and future interactions.

All subject groups participated during school hours, i.e. as part of a compulsory course. The role of the teachers was limited to supervision; all instructions and technical support, if necessary, were provided by the study leaders. Participation in both variants was in teams of two per unit to allow for collaboration and mutual assistance.

3.2 Survey

Altogether, a total of n = 110 (53 females, 56 males, 1 diverse) students from German gymnasiums participated in the study between June 2021 and July 2022. The participants were students from the 9th to the 12th grade (m = 10.295). N = 66 (33 females, 33 males, 0 diverse) participated in the AFT, and then n = 44 (20 females, 23 males, 1 diverse) joined the VFT the year after. All the schools were contacted and encouraged to participate at the same time. The division of the participating classes into the VFT and AFT was randomly based on the time of registration and the availability of the schools and teachers. All the surveys were conducted on the participation dates, directly before and after the respective interventions. All procedures were performed in compliance with relevant laws and institutional guidelines and were approved by the appropriate institutional committee institution's ethics committee ("Kommission Forschung und Verantwortung").

Depending on how they identified themselves, participants indicated their gender as m, f, or d; the diverse category was only chosen once and has, therefore, been disregarded in the gender comparisons for statistical reasons. Since, depending on the class level, different levels of knowledge and maturity of the students are to be expected, this was also recorded to ensure comparability of the test (VFT) and control (AFT) groups due to the relatively wide range of four class levels.

In the survey, subject-specific knowledge is the central measure of the success of the interventions. Specifically, this refers to environmental science knowledge and methods, which have strong links to geography and (mostly through a concrete application reference) to modern technology. A review of existing knowledge tests to measure the participants' subject-specific knowledge acquirements, stagnations, or even declines during the interventions was unsatisfactory for scope and content reasons (Huizenga et al., 2009; Kaiser & Frick, 2002). Finally, 15 directly content-related test items were created to meet the needs of this study. The items are statements that could be checked as true, false, or do not know. Items that were correctly checked as true or false were treated as "knowing," and items incorrectly checked as true or false or checked as do not know were treated as "not knowing." See the two examples a (= false statement) and b (= true statement) beyond (see full set of applied instruments in Appendix A).

a. A virtual environment model is an exact copy of a certain area of the real world.
   ◯ true ◯ false ◯ don't know
b. Nowadays, scientists use self-piloting camera drones, lasers on airplanes and artificial intelligence to study nature and the environment.
   ◯ true ◯ false ◯ don't know

The identical subject-specific knowledge scale was used for the VFT and the AFT. During the analysis, a variable for knowledge acquisition was created by using the score differences between the pre- (SSK_1) and post-testing (SSK_2) to quantify the actual gain that could have been achieved through the respective interventions.

The Modern Technology Attitude Index (MTAI) was recently developed and has proven to be a suitable tool for measuring and differentiating between attitude dimensions related to the content of technology (Bengel & Peter, 2021)). The MTAI consists of 14 items measuring the three main psychometric dimensions of attitudes: the cognitive, affective, and conative response behavioral dimensions (Eagly & Chaiken, 2011). Further, these dimensions can be categorized based on two technology-aversion scales, intimidation (INT) and loss of control (LOC), and third, a technology-affirmation scale with benefits and easement (BAE). Originally applied to observe pre-service teachers' attitudes, the latest studies show a broader scope of use, including secondary school students (Bengel & Peter, 2022). The tool was, therefore, chosen to identify potential changes within our test group in the virtual setting. The 14 items of the MTAI were rated on a Likert scale with four possible answers: (1) strongly disagree, (2) tend to disagree, (3) tend to agree, and (4) fully agree (Nemoto & Beglar, 2014). For the subsequent analysis, the means of the three sub-scales were calculated as test values (Bühner, 2011). In contrast to the biographical parameters, the attitudes were also queried again directly after the VFT intervention using the same instrument to observe potential changes (see Table 1 and Figure 2).

Table 1. Surveyed parameters of the VFT and AFT groups at the first (pre) and second (post) times of inquiry

Group	Parameters	Pre-testing	Post-testing
VFT (n = 44)	Biographical parameters	•	
	Subject-specific knowledge	•	•
	Content-related attitudes (MTAI)	•	•
AFT (n = 66)	Biographical parameters	•	
	Subject-specific knowledge	•	•

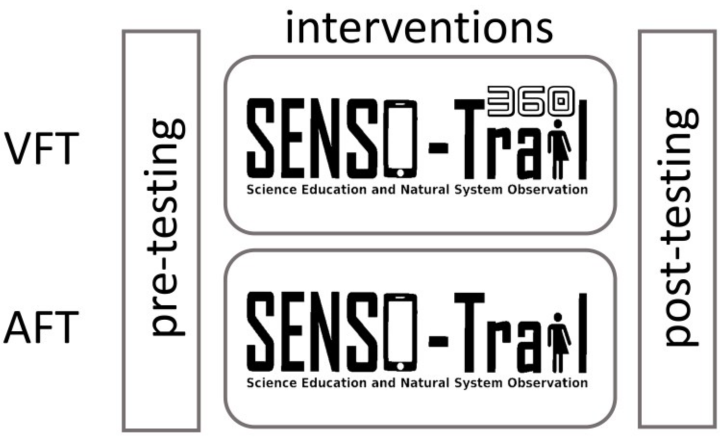

Figure 2. Research design

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In other cases, for example, gender-specific differences in attitudes could be expected due to the environmental science content of the measure and the associated effects on learning success (Anderson & Krettenauer, 2021; Desrochers et al., 2019). This can be ruled out in the present case, as the results of a preliminary study in a setting comparable to this study have already shown (see Bengel & Peter, 2022).

3.3 Data Analysis

For the descriptive methods and comparisons, the free statistical software JASP (version 0.14.1) was used (Wagenmakers, 2021). The data presented in this study are openly available via the research data repository of Philipps University Marburg: https://data.uni-marburg.de/entities/dataset/e3d52270-b8e6-47b6-b501-0395b6bf9155 (accessed on July 1, 2024).

For the identification of potential disparities in the students' grades and the comparison of the prior and acquired subject-specific knowledge scores in both groups, a Student's t-test for independent values was performed. The same procedure was used to compare males' and females' subject-specific knowledge and content-related attitudes scores within the VFT group. For cases of violated normality or equality of variances, either Welch's t or Mann-Whitney tests were used instead. A paired Student's t-test and a respective Wilcoxon signed-rank test were performed for cases with violated normality to analyze all the participants' pre- and post-subject-specific knowledge scores and the VFT group's attitudes pre- and post-scores. The level of significance was set at 0.05 (Bühner, 2011).

4. Results

4.1 Prerequisites

Before examining the VFT (n = 44) and AFT (n = 66), possible differences in their attributes, such as grade and subject-specific previous knowledge (SSK_1), had to be determined to ensure comparability. The t-test showed no significant differences comparing the average grades of both groups. However, there is a significant difference in terms of previous knowledge (SSK_1) between VFT and AFT group. This, as can be seen in Figure 3, was revealed by a difference of 0.081 in the means (t_{Welch} = 2.471, p = 0.015), meaning that such knowledge was slightly higher in the VFT group than in the AFT group.

4.2 Acquired Subject-Specific Knowledge

In a second step, the acquired subject-specific knowledge of both groups, which can be seen as the difference between the SSK_2 and SSK_1 scores in Figure 4, was compared in another t-test. It is clear from the graphs that, with the exception of a few subjects where there was no increase in knowledge, the majority of subjects showed an increase in knowledge in both cases. Figure 5 shows how the mean values of acquired knowledge in both groups did not differ significantly, with a variance of 0.001 (t_{Welch} = 0.030, *p* = 0.976).

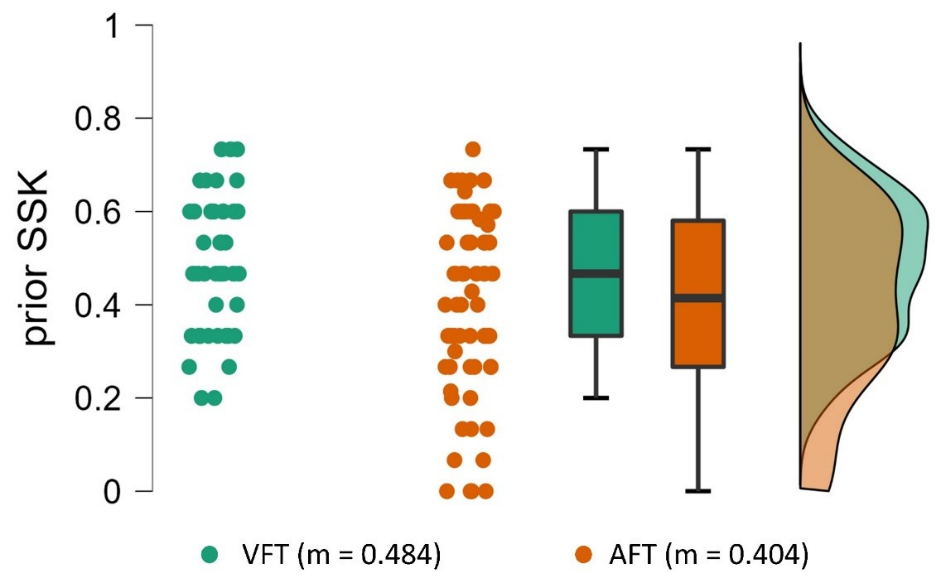

Figure 3. Prior subject-specific knowledge (SSK_1) scores in the AFT and VFT with means (m)

4.3 Attitudinal Changes

In the next section of our research, we wanted to analyze content-related attitudes. The goals were to observe whether or not there are significant changes in attitudes towards technology as a result of participation in the virtual experience and, subsequently, identify potential gender effects.

A comparison of the whole test group's (n = 44) pre- and post-values on the affective dimension of intimidation (INT) did not show any significant effects. The result was different for the other two scales. Here a Wilcoxon signed-rank test indicated that the mean post-test ranks of the perceived loss of control (LOC) were significantly lower than the mean pre-test ranks (z = 3.319, *p* = 0.001; see Figure 6).

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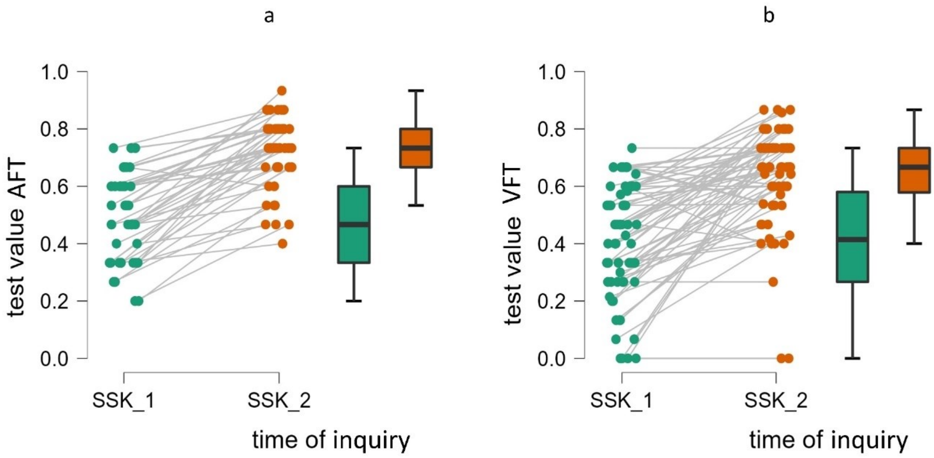

Figure 4. Subject-specific knowledge gains of the AFT (a) and VFT (b) between the first and second times of inquiry

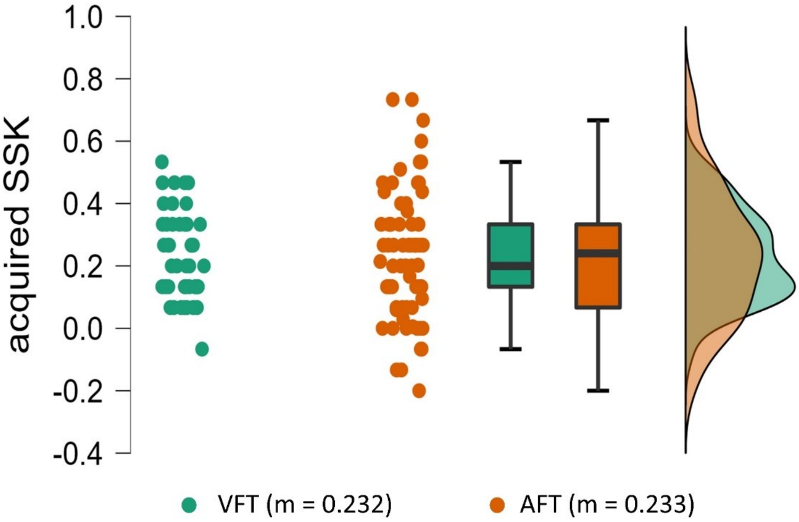

Figure 5. Acquired subject-specific knowledge in the AFT and VFT with means (m)

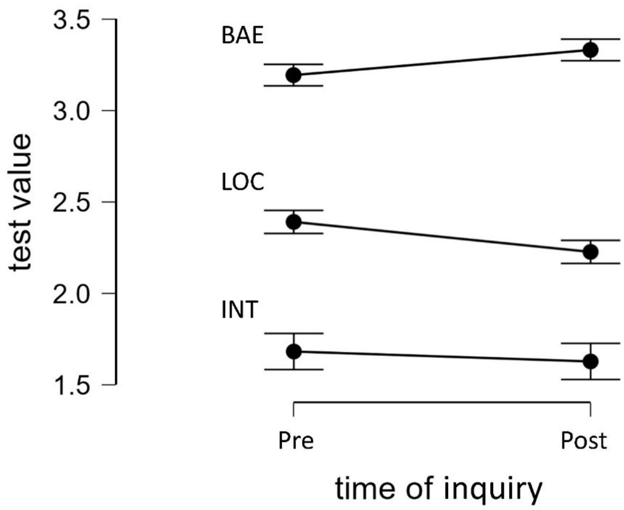

Figure 6. Content-related attitudes development of the VFT participants between the first and second times of inquiry

For the dimension of perceived benefits and easement (BAE), the Wilcoxon signed-rank test indicated that the mean post-test ranks were significantly higher than the mean pre-test ranks (z = -2.665, *p* = 0.008; see Figure 6).

4.4 Gender Analysis

Next, further t-tests were used to analyze gender-specific differences. These were conducted for subject-specific knowledge and the three dimensions of attitudes before and after the interventions.

A gender comparison of subject-specific knowledge before and after the interventions shows a significant increase in the knowledge of both groups, as mentioned above. Further, there is no significant gender difference in either the initial situation before the interventions or at the second time of inquiry after them.

Other results are observed when it comes to content-related attitudes. At the first time of the inquiry, females showed a significantly higher score on the INT scale than males (U = 322.5000, p = 0.022). At the second point in time, the score for females had dropped from an average of 1.90 to 1.78 and was, thus, close enough to the nearly unchanged value for males that a statistical difference (U = 274.0000, p = 0.276) could no longer be proven (Figure 7).

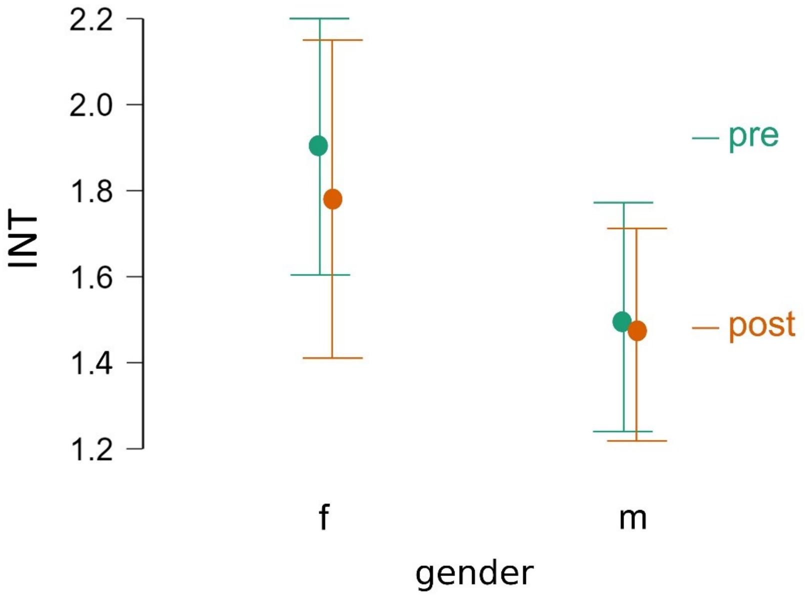

Figure 7. INT pre- and post-scores of the female and male VFT participants

The same effect can be reported for the second aversive dimension measured with the LOC scale. Although there was a cross-gender decline in the test values, the gender difference was also only significant at the first point in time ($t_{Student}$ = 2.396, p = 0.021), while it was no longer significant at the second point ($t_{Student}$ = 1.238, p = 0.223) due to a greater decline in the test scores among the females (Figure 8).

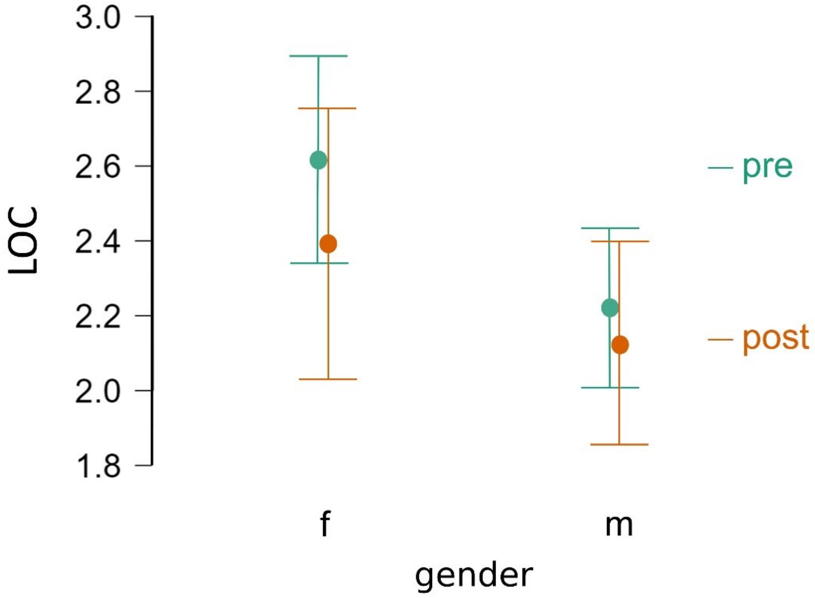

Figure 8. LOC pre- and post-scores of the female and male VFT participants

Regarding the affirmative scale for benefits and easement (BAE), there were no significant gender-specific differences.

5. Discussion

5.1 Discussion of Results

In the first step of our research, we wanted to investigate how a game-based VFT compares to its AFT counterpart in terms of imparting subject-specific knowledge. Observing the pre-conditions of comparability, despite no measurable differences in grades, we identified significantly lower levels of prior knowledge within the AFT group. However, the positive differences in the acquired knowledge between both times of inquiry among both groups did not differ at all, and, in fact, they were nearly identical. This leads to the conclusion that regardless of the prerequisites, both concept variants work similarly well and confirm earlier assumptions in this regard (Klippel et al., 2019; Ruberto et al., 2017).

The fact that despite the considerable differences in the settings of both variants students' knowledge acquirements were almost identical can be interpreted in two ways. First, it could be that the aspect of the spatial environment no longer has a subjective influence, since young people of this generation already act as naturally in virtual contexts as they do in real ones. Therefore, it might be that the virtual or actual setting parameters do not matter as long as the core educational concept remains the same. The second attempt at an explanation seems to be more likely but rather complex at the same time. It includes the assumption that various external influencing factors had uncontrolled effects in both settings but canceled each other out in the aggregate. Thus, it is easy to imagine that the AFT group experienced many opportunities for distraction due to the open setting in an actual forest, while the participation that took place in a computer room, which is relatively similar to a classroom, was more focused in this regard. At the same time, of course, the experience of actually being in the forest could have left a more authentic and, therefore, positive impression on the learners, as already described by Siegmund et al. (2013), and, thus, have had a positive effect on the learning process. This scenario is only one example of the many ways in which parameters that were not recorded might have had positive or negative effects on the learners' performances but could compensate each other for the bottom line. The positive effects reported in studies of VFTs in geography or serious games in VR may also exist in this case, but they do not seem to outweigh those of actual physical experiences (Firomumwe, 2021; Ho et al., 2022).

For technology-supported geography lessons, this means that VFTs are an attractive alternative to AFTs, at least when it comes to the pure acquisition of subject knowledge. VFTs offer some organizational advantages over AFTs; for example, they are often cheaper, less time-consuming, and more accessible than their counterparts (Klippel, et al. 2019). However, in geography education, other competencies are important in addition to subject knowledge. Regarding many of them, it is still unclear whether they might not be better promoted by AFTs, in which application-oriented encounters with real objects and phenomena, which are usually highly valued in geography education, are possible (Siegmund et al., 2013). In addition, the educational use of computers and modern technology must continue to be treated with caution, given the potential negative physical and mental impacts on learners (Wang et al., 2023; Wood et al., 2013). Anyway, for certain geographical competencies, there is already evidence of the advantage of VFTs, e.g., in the promotion of complex problem solving and spatial intelligence (Salsabila et al., 2022). At any rate, spatial perception in virtual worlds will be a major issue to be addressed by geography as a science of human-environment relations, but also as a subject of education.

Although we must leave it to subsequent studies to further illuminate this topic, our investigations of the influences of the game-featured virtual learning worlds on visitors' attitudes may represent another valuable contribution to the role of computers in education. Other than to be expected from the results of Pirker and Dengel's (2021) literature review there was no general effect on the affective dimension of the participants' attitudes in this study since the perceived intimidation related to modern technology did not change significantly. It is noteworthy that in this context the behavioral (loss of control) and cognitive dimensions (benefits and easement) did show demonstrably changes in favor of affirmative modern technology attitudes. The latter fits with the findings of Cárdenas-Sainz (2022), who were able to demonstrate effects on perceived ease of use through the use of modern educational technology. It can thus be concluded that at least one of the MTAI's aversive scales, together with its affirmative scale, indicates a change toward more positive attitudes in relation to modern technology due to the effects of the DGBL-featured VFT intervention. From the perspective of technological literacy promotion, this is a valuable finding which shows that the pedagogical use of appropriate technology itself is suitable for positively influencing attitudes towards these very devices and their purposes.

The gender-specific differences in attitudes and the respective changes in this study are particularly interesting. At first glance, it already becomes clear that it was a sensible decision to assess attitudes toward modern technology in several dimensions, as previous studies suggested (Cai et al., 2017). As expected from the previous results by Bengel and Peter (2021, 2022) and Svenningsson et al. (2022), here too, among the females a significantly higher score was initially found in the affective dimension, which was represented by the aversive sub-scale for intimidation. Interestingly, there were also differences at the cognitive level, which was represented by the perceived loss of control. The female participants, therefore, showed significantly higher values on both aversion scales than their male counterparts. After participation, however, no clear differences between female and male participants could be detected on either scale. Despite the different gender associations with gaming as e.g. described by Kelly et al. (2023), the game-based approach combined with a virtual experience seems to have a positive impact on female participants, when it comes to a reduction of aversive attitudes towards technology. It is worth noting two things concerning this: First, despite clear attitudinal differences between gender and attitudinal changes over time, none of these facts seems to affect the learning success of either of the sexes. This is in line with current results, according to which content-related attitudes do not influence the acquisition of subject-specific knowledge in respective interventions (Bengel & Peter, 2022; Pirker & Dengel, 2021). Second, our results suggest that the DGBL-featured VFT could support a positive development toward closing attitudinal gender gaps within modern technology. These findings are not only a valuable contribution to the development of gender-responsive education. Even more, they support the development of similar technology-based game-featured approaches that effectively reduce the gender gap and equally promote technological literacy.

5.2 Discussion of Limitations

The significance of our study may be limited due to a comparatively small sample size. However, it should be noted that related methodological implications were taken into account in all statistical analyses.

The imbalance in terms of the sizes of the two groups can be explained by the fact that, during a pandemic, such as the one transpiring when this study was conducted, it is far easier to recruit school classes for an open-air activity than one in computer rooms.

Based on these results, it would perhaps be going too far to assume that interventions such as those described here provide a general solution for closing the gender gap. Nevertheless, the corresponding effects cannot be dismissed out of hand, and the presented approaches can make a positive contribution.

We have to admit that this study is a comparison reduced to a few relevant factors. Possible effects caused by the design of the applications, independent of the didactic approaches and content used, cannot be ruled out. Other constellations of indoor and outdoor educational approaches and the manifold possibilities offered by digital technologies and game-based learning, such as augmented or mixed reality, could not be included. The same applies to other potential influencing factors and pre-conditions of the participants. Interest, motivation, perceived self-efficacy, and additional geographical competencies are just a few variables that follow-up studies or other scholars in this field might want to investigate further.

It should be noted as well that due to the lack of respective instruments, we were not able to survey technological literacy in its complex entirety (Verbeek, 2024). However, with parameters of subject-specific knowledge and content-related attitudes, we did measure variables that have a proven effect on this construct (Ardies et al., 2013). By promoting these attributes, we can therefore assume that technological literacy is directly promoted.

6. Conclusions

The present study allows us to add results for the positive effects of DGBL (e.g. Camacho-Sánchez et al., 2022) and VFT concepts (e.g. Robledo & Prudente, 2022) as a combined approach. In summary, we can confirm that game-based VFTs and game-based AFTs can equally effectively convey subject-specific knowledge (Klippel et al., 2019; Robledo & Prudente, 2022). Even if the attitudes towards modern technology itself do not seem to have an effect on knowledge acquisition in VFTs, these interventions seem able to promote affirmative attitudes towards modern technologies in general and reduce aversions. Unlike in comparable studies (Robledo & Prudente, 2022; Araujo-Junior & Bodzin, 2022), the content reference of the attitudes establishes a direct link to the modern technology used. The resulting effect is particularly pronounced among females. A gender gap represented by higher intimidation levels and the perceived loss of control among females, was measured before the intervention and could both be equalized during the participation. Through targeted knowledge transfer, but also through the positive effects on participants' attitudes towards modern technology, this pedagogical approach represents a valuable contribution to the promotion of technological literacy, which might be crucial for future educational practices. Our findings do not lead us to make a conclusive recommendation for the use of modern technology in either virtual or actual settings, except that both are suitable for education in extracurricular settings. Moreover, they show an overarching potential of DGBL-featured and virtually implemented approaches on technology that should be promoted, further developed, and further investigated in their individual but overlapping areas. The exploration of human-environment relations in virtual spaces lead to a new aspect of geographical education with unknown potential. However, what became clear is that there does not seem to be a need for targeted "technology education" as such, when it comes to the promotion of technological literacy. Practitioners should draw the conclusion that positive results can also be achieved if elements of technology education are combined in a transdisciplinary manner (in our case with geographical environmental content) and the technology itself is part of the materials used in the form of computers, devices or apps. These findings create a broad field for different approaches that can contribute to the promotion of technological literacy. Through the targeted and conscious use of new technologies, modern learning spaces can be created, not only for innovative geography lessons but also for the general promotion of technological literacy in society regardless of gender or virtual and real spatial environments.

Funding: This research was funded by the LOEWE program of the Hessian State Ministry for Higher Education, Research, and the Arts, Germany

Data Availability Statement: The data presented in this study are openly available via the research data repository of Philipps University Marburg: https://data.uni-marburg.de/entities/dataset/e3d52270-b8e6-47b6-b501-0395b6bf9155 (accessed on July 1, 2024).

Conflicts of Interest: The authors declare no conflict of interest.

Appendix A – Survey Instruments

Modern Technology Attitude Index (MTAI) in applied language*[1] *(German):

Bitte bewerte jede Aussage aus deiner persönlichen Sicht und gib an, ob sie für dich

++ voll zutrifft
+ eher zutrifft
- eher nicht zutrifft oder
-- überhaupt nicht zutrifft

[MTA01] Moderne Technik ist mir unangenehm, weil ich sie nicht verstehe. (INT)

++	+	-	- -	*verstehe ich nicht*
◯	◯	◯	◯	[ ]

[MTA02] Die Menschen werden zu Sklaven der modernen Technik. (LOC)

++	+	-	- -	*verstehe ich nicht*
◯	◯	◯	◯	[ ]

[MTA03] Moderne Technik ist für viele der guten Dinge verantwortlich die wir genießen. (BAE)

++	+	-	- -	*verstehe ich nicht*
◯	◯	◯	◯	[ ]

[MTA04] Bald wird unser Leben von moderner Technik gesteuert. (LOC)

++	+	-	- -	*verstehe ich nicht*
◯	◯	◯	◯	[ ]

[1] An English translation of the survey instruments is available upon request to the corresponding author. However, the English translation was not used for any data collection so far and has not been checked for its quality in this respect. Therefore, the authors advise against using the items without prior testing.

[MTA05] Ich fühle mich von moderner Technik eingeschüchtert. (INT)
++ + - - - *verstehe ich nicht*
◯ ◯ ◯ ◯ [ ]

[MTA06] Moderne Technik *entmenschlicht* die Gesellschaft. (LOC)
++ + - - - *verstehe ich nicht*
◯ ◯ ◯ ◯ [ ]

[MTA07] Die moderne Technik kann den Menschen viel mühsame Arbeit ersparen. (BAE)
++ + - - - *verstehe ich nicht*
◯ ◯ ◯ ◯ [ ]

[MTA08] Der Einsatz moderner Technik verbessert unseren Lebensstandard. (BAE)
++ + - - - *verstehe ich nicht*
◯ ◯ ◯ ◯ [ ]

[MTA09] Moderne Technik macht aus Menschen Nummern. (LOC)
++ + - - - *verstehe ich nicht*
◯ ◯ ◯ ◯ [ ]

[MTA10] Moderne Technik schreckt mich ab, weil sie so komplex ist. (INT)
++ + - - - *verstehe ich nicht*
◯ ◯ ◯ ◯ [ ]

[MTA11] Moderne Technik wird uns in eine glänzende neue Ära führen. (BAE)
++ + - - - *verstehe ich nicht*
◯ ◯ ◯ ◯ [ ]

[MTA12] Bald wird unsere Welt vollständig von Technik beherrscht. (LOC)
++ + - - - *verstehe ich nicht*
◯ ◯ ◯ ◯ [ ]

[MTA13] Mit moderner Technik wird das Leben einfacher. (BAE)
++ + - - - *verstehe ich nicht*
◯ ◯ ◯ ◯ [ ]

[MTA14] Moderne Technik ist schwer zu verstehen und es frustriert mich mit ihr zu arbeiten. (INT)
++ + - - - *verstehe ich nicht*
◯ ◯ ◯ ◯ [ ]

Subject-specific Knowledge Test in applied language (German):

Bitte gib an, ob die nachfolgenden Aussagen richtig oder falsch sind.

[KN01] Für den Schutz von Natur und Umwelt setzen Wissenschaftler*innen heutzutage selbststeuernden Kamera-Drohnen, Laser an Flugzeugen und künstliche Intelligenzen ein.
◯ richtig
◯ falsch
◯ weiß ich nicht

[KN02] Auch unbelebte Elemente, wie die Form der Erdoberfläche oder das Klima sind Teile von Ökosystemen.
◯ richtig
◯ falsch
◯ weiß ich nicht

[KN03] Wenn viele Daten an unterschiedlichen Orten und zum gleichen Zeitpunkt gesammelt werden sollen, ist eine Messung mit automatischen Sensoren meistens aufwendiger, als wenn es eine Person von Hand erledigen würde.
◯ richtig
◯ falsch
◯ weiß ich nicht

[KN04] Während Menschen manche Dinge erst neu lernen müssen, bevor sie bestimmte Aufgaben erfüllen können, erhalten künstliche Intelligenzen ihre gesamten Fähigkeiten schon mit ihrer Programmierung.
◯ richtig
◯ falsch
◯ weiß ich nicht

[KN05] Durch Fernerkundung mit Satelliten lässt sich ein bestimmtes Untersuchungsgebiet genauer betrachten, als es mit Aufnahmen von Kamera-Drohnen möglich ist.
◯ richtig
◯ falsch
◯ weiß ich nicht

[KN06] An einem Baum kann sich zum selben Zeitpunkt die Luftfeuchtigkeit in seiner Krone von der an seinem Stamm deutlich unterscheiden.

◯ richtig
◯ falsch
◯ weiß ich nicht

[KN07] Unter Fernerkundung versteht man z. B. die Betrachtung physischer Eigenschaften der Erdoberfläche aus der Luft oder aus dem All.

◯ richtig
◯ falsch
◯ weiß ich nicht

[KN08] Pflanzen sammeln tagsüber Wärme von der Sonne und speichern sie nachts in den Flüssigkeiten (Saftfluss) in ihrem Stamm.

◯ richtig
◯ falsch
◯ weiß ich nicht

[KN09] Lebewesen haben selbst keinen Einfluss auf das Klima in ihrem Lebensraum.

◯ richtig
◯ falsch
◯ weiß ich nicht

[KN10] Die Ultraschallrufe von Fledermäusen können zwar von menschlichen Ohren nicht gehört, aber mit herkömmlichen Radios empfangen werden.

◯ richtig
◯ falsch
◯ weiß ich nicht

[KN11] Eine künstliche Intelligenz ist im Prinzip nichts anderes als ein kompliziertes Computerprogramm das auf Rechnern läuft.

◯ richtig
◯ falsch
◯ weiß ich nicht

[KN12] Ein virtuelles Umweltmodell ist eine exakte Kopie eines bestimmten Ausschnittes der realen Welt.

◯ richtig
◯ falsch
◯ weiß ich nicht

[KN13] Dank moderner Technik können Bäume sprechen, dafür werden ihnen intelligente Microchips eingesetzt.

◯ richtig
◯ falsch
◯ weiß ich nicht

[KN14] Es ist technisch noch nicht möglich die Bewegungen von Tieren in ihrem Lebensraum genau zu verfolgen, <u>ohne</u> dass diese dazu einen Sender an sich tragen müssen.

◯ richtig
◯ falsch
◯ weiß ich nicht

[KN15] Wissenschaftler*innen können virtuelle Modelle von Ökosystemen erstellen, um damit verschiedene Zukunftsszenarien vorherzusagen.

◯ richtig
◯ falsch
◯ weiß ich nicht

References

Agbo, F. J., Oyelere, S. S., Suhonen, J., & Tukiainen, M. (2022). Design, development, and evaluation of a virtual reality game-based application to support computational thinking. *Educational Technology Research and Development*, 1–33. https://doi.org/10.1007/s11423-022-10161-5

Allert, H., & Richter, C. (2017). Kultur der Digitalität statt digitaler Bildungsrevolution. *Pädagogische Rundschau*, *71*(1), 19–32. https://docserver.ingentaconnect.com/deliver/connect/plg/00309273/v71n1/s2.pdf?expires=1674040418&id=0000&titleid=72010663&checksum=1A35B2F218122E7D27713048B13328CF&host=https://www.ingentaconnect.com

Al-Mugheed, K., Bayraktar, N., Al-Bsheish, M., AlSyouf, A., Aldhmadi, B. K., Jarrar, M., & Alkhazali, M. (2022). Effectiveness of game-based virtual reality phone application and online education on knowledge, attitude and compliance of standard precautions among nursing students. *PloS One*, *17*(11), e0275130. https://doi.org/10.1371/journal.pone.0275130

Alsaqqaf, A. Z. (2022). *Conceptual Framework for Designing Virtual Field Trip Games.* Durham University, Durham, United Kingdom. http://etheses.dur.ac.uk/14875/1/VFTG-Final.pdf?DDD4

Anderson, D. J. & Krettenauer T. (2021). Connectedness to Nature and Pro-Environmental Behaviour from Early Adolescence to Adulthood: A Comparison of Urban and Rural Canada. *Sustainabilty,* 13(7), 3655. https://doi.org/10.3390/su13073655

Araujo-Junior, R. M., & Bodzin, A. M. (2022). Effects of a place-based digital gameful learning experience on middle school students' watershed literacy and attitudes about desktop virtual reality gameplay. *Interactive Learning Environments*, 1–19. https://doi.org/10.1080/10494820.2022.2118785

Ardies, J., Maeyer, S. de, & Gijbels, D. (2013). Reconstructing the Pupils Attitude Towards Technology-survey. *Design and Technology Education: An International Journal*, *18*(1), 8–19. https://files.eric.ed.gov/fulltext/EJ1007134.pdf

Bätz, K., Wittler, S., & Wilde, M. (2010). Differences between boys and girls in extracurricular learning settings. *International Journal of Environmental & Science Education*, *5*(1), 51–64. https://files.eric.ed.gov/fulltext/EJ884411.pdf

Bengel, P. T., & Peter, C. (2021). Modern Technology in Geography Education – Attitudes of Pre-Service Teachers of Geography on Modern Technology. *Education Science, 11(11), 708.* https://doi.org/10.3390/educsci11110708

Bengel, P. T., & Peter, C. (2022). Technology in Nature – mDGBL as a Successful Approach to Promote Complex Contents?. *Sustainabilty, (15(1), 633.* https://doi.org/10.3390/su15010633

Buelin, J., Daugherty, M. K., Hoepfl, C., Kelley, T., Loveland, T., Moye, J. & Summer, A. (2019). ITEEA Standards for Technological Literacy Revision Project: Background, Rationale, and Structure. *ITEEA.* https://assets-002.noviams.com/novi-file-uploads/iteea/standards/STLRevisionRationale06_28_2019.pdf

Bruch, K. M., Braun, H.-W., & Teel, S. (2011). Evaluating the Effectiveness of Live Interactive Virtual Explorations Involving a Hard-to-Reach Native American Earth Lodge and a Pacific Island Volcanoes Site. *Journal of Interpretation Research*, *16*(1), 67–72. https://doi.org/10.1177/109258721101600105

Bühner, M. (2011). *Einführung in die Test- und Fragebogenkonstruktion* (3., aktualisierte und erweiterte Auflage). *Always learning*. Pearson.

Cai, Z., Fan, X., & Du, J. (2017). Gender and attitudes toward technology use: A meta-analysis. *Computers & Education*, *105*, 1–13. https://doi.org/10.1016/j.compedu.2016.11.003

Çaliskan, O. (2011). Virtual field trips in education of earth and environmental sciences. *Procedia - Social and Behavioral Sciences*, *15*, 3239–3243. https://doi.org/10.1016/j.sbspro.2011.04.278

Camacho-Sánchez, R., Rillo-Albert, A., & Lavega-Burgués, P. (2022). Gamified Digital Game-Based Learning as a Pedagogical Strategy: Student Academic Performance and Motivation. *Applied Sciences*, *12*(21), 11214. https://doi.org/10.3390/app122111214

Cárdenas-Sainz, B. A., Barrón-Estrada, M. L., Zatarain-Cabada, R., & Ríos-Félix, J. M. (2022). Integration and acceptance of Natural User Interfaces for interactive learning environments. *International Journal of Child-Computer Interaction*, *31*, 100381. https://doi.org/10.1016/j.ijcci.2021.100381

Cesário, V., & Nisi, V. (2022). Designing with teenagers: A teenage perspective on enhancing mobile museum experiences. *International Journal of Child-Computer Interaction*, *33*, 100454. https://doi.org/10.1016/j.ijcci.2022.100454

Cheng, K.-H., & Tsai, C.-C. (2019). A case study of immersive virtual field trips in an elementary classroom: Students' learning experience and teacher-student interaction behaviors. *Computers & Education*, *140*, 103600. https://doi.org/10.1016/j.compedu.2019.103600

Desrochers, J. E., Albert, G., Milfont, T. L., Kelly, B., & Arnocky, S. (2019). Does Personality Mediate the Relationship Between Sex and Environments? Personality and individual differences, 147, 204-213. https://doi.org/10.1016/j.paid.2019.04.026

Dyrenfurth, M. J., & Kozak, M. R. (1991). *Technological literacy*. 40th yearbook of the Council on Technology Teacher Education. *Peoria, IL: Glencoe*.

Eagly, A. H., & Chaiken, S. (2011). *The psychology of attitudes* [repr.]. Wadsworth Cengage Learning.

Edwards, R. C., & Larson, B. M. H. (2020). When screens replace backyards: strategies to connect digital-media-oriented young people to nature. *Environmental Education Research*, *26*(7), 950–968. https://doi.org/10.1080/13504622.2020.1776844

Firomumwe, T. (2021). Exploring the Opportunities of Virtual fieldwork in Teaching Geography During Covid-19 Pandemic. *International Journal of Geography and Geography Education.* Advance online publication. https://doi.org/10.32003/igge.973983

Francis, J., Ball, C., Kadylak, T., & Cotten, S. R. (2019). Aging in the Digital Age: Conceptualizing Technology Adoption and Digital Inequalities. In *Ageing and Digital Technology* (pp. 35–49). Springer. https://doi.org/10.1007/978-981-13-3693-5_3

García de la Vega, A. (2022). A Proposal for Geography Competence Assessment in Geography Fieldtrips for Sustainable Education. *Sustainability*, *14*(3), 1429. https://doi.org/10.3390/su14031429

Giannakas, F., Kambourakis, G., Papasalouros, A., & Gritzalis, S. (2018). A critical review of 13 years of mobile game-based learning. *Educational Technology Research and Development*, *66*(2), 341–384. https://doi.org/10.1007/s11423-017-9552-z

Gram-Hanssen, K. (2008). Consuming technologies – developing routines. *Journal of Cleaner Production*, *16*(11), 1181–1189. https://doi.org/10.1016/j.jclepro.2007.08.006

Huff, I., Ellis, G. W., McAuliffe, L., Ellis, S. K., & McGinnis-Cavanaugh, B. (2012). Engaging the Imagination of Young People to Increase Technical Literacy. *American Society for Engineering Education*, 1–15. https://strategy.asee.org/engaging-the-imagination-of-young-people-to-increase-technical-literacy

Huizenga, J., Admiraal, W., Akkerman, S., & Dam, G. ten (2009). Mobile game-based learning in secondary education: engagement, motivation and learning in a mobile city game. *Journal of Computer Assisted Learning*, *25*(4), 332–344. https://doi.org/10.1111/j.1365-2729.2009.00316.x

Ho, S.-J., Hsu, Y.-S., Lai, C.-H., Chen, F.-H., & Yang, M.-H. (2022). Applying Game-Based Experiential Learning to Comprehensive Sustainable Development-Based Education. *Sustainability*, *14*(3), 1172. https://doi.org/10.3390/su14031172

Islahi, F., & Nasrin, N. (2019). Exploring Teacher Attitude towards Information Technology with a Gender Perspective. *Contemporary Educational Technology*, *10*(1). https://doi.org/10.30935/cet.512527

Kaiser, F. G., & Frick, J. (2002). Entwicklung eines Messinstrumentes zur Erfassung von Umweltwissen auf der Basis des MRCML-Modells. *Diagnostica*, *48*(4), 181–189. https://doi.org/10.1026//0012-1924.48.4.181

Kelly, D., Nic Giolla Easpaig, B., & Castillo, P. (2023). 'You Game Like a Girl': Perceptions of Gender and Competence in Gaming. *Games and Culture*, *18*(1), 62–78. https://doi.org/10.1177/15554120221077730

Khasawneh, O. Y. (2023). Technophobia: How Students' Technophobia Impacts Their Technology Acceptance in an Online Class. *International Journal of Human–Computer Interaction*, *39*(13), 2714–2723. https://doi.org/10.1080/10447318.2022.2085398

Klippel, A., Zhao, J., Jackson, K. L., La Femina, P., Stubbs, C., Wetzel, R., Blair, J., Wallgrün, J. O., & Oprean, D. (2019). Transforming Earth Science Education Through Immersive Experiences: Delivering on a Long Held Promise. *Journal of Educational Computing Research*, *57*(7), 1745–1771. https://doi.org/10.1177/0735633119854025

Klippel, A., Zhao, J., Oprean, D., Wallgrün, J. O., Stubbs, C., La Femina, P., & Jackson, K. L. (2020). The value of being there: Toward a science of immersive virtual field trips. *Virtual Reality*, *24*(4), 753–770. https://doi.org/10.1007/s10055-019-00418-5

Knoblich, L. (2020). Digital gestützte Biodiversitätsexkursionen. *Biologie in Unserer Zeit*, *50*(2), 134–142. https://doi.org/10.1002/biuz.202010703

García de la Vega, A. (2022). A Proposal for Geography Competence Assessment in Geography Fieldtrips for Sustainable Education. *Sustainability*, *14*(3), 1429. https://doi.org/10.3390/su14031429

Latour, B. (2021). Where Are The Missing Masses? The Sociology of a Few Mundane Artefacts. In D. G. Johnson & J. M. Wetmore (Eds.), *Inside technology. Technology and society: Building our sociotechnical future* (Second edition). The MIT Press.

Lave, J., & Wenger-Trayner, É. (2011). *Situated learning: Legitimate peripheral participation* (24. print). *Learning in doing*. Cambridge Univ. Press.

Liang, C., Song, Y., & Wang, B. (2022). The Influence of Social Function of Mobile Game Augmented Reality and Virtual Reality Environment on Mobile Phone Users' Addiction. *Wireless Communications and Mobile Computing*, *2022*, 1–8. https://doi.org/10.1155/2022/2903124

Marth, M., & Bogner, F. X. (2019). Monitoring a gender gap in interest and social aspects of technology in different age groups. *International Journal of Technology and Design Education*, *29*(2), 217–229. https://doi.org/10.1007/s10798-018-9447-2

Merchant, Z., Goetz, E. T., Cifuentes, L., Keeney-Kennicutt, W., & Davis, T. J. (2014). Effectiveness of virtual reality-based instruction on students' learning outcomes in K-12 and higher education: A meta-analysis. *Computers & Education*, *70*, 29–40. https://doi.org/10.1016/j.compedu.2013.07.033

Morawski, M., & Wolff-Seidel, S. (2023). Gaming & Geography (Education): Gaming and Geography (Education): A Model of Reflexive Analysis of Space and Action in Video Games. *European Journal of Geography*, *14*(3), 1–19. https://doi.org/10.48088/ejg.m.mor.14.3.001.019

Nemoto, T., & Beglar, D. (2014). Developing Likert-scale questionnaires. In N. Sonda & A. Krause (Chair), *JALT2013.* Symposium conducted at the meeting of Temple University, Japan. https://jalt-publications.org/sites/default/files/pdf-article/jalt2013_001.pdf

Niiranen, S. (2016). *Increasing girls' interest in technology education as a way to advance women in technology* [Dissertation]. University of Jyväskylä, Jyväskylä http://urn.fi/URN:ISBN:978-951-39-6736-9

Nikolaou, A., Schwabe, A., & Boomgaarden, H. (2022). Changing social attitudes with virtual reality: a systematic review and meta-analysis. *Annals of the International Communication Association*, *46*(1), 30–61. https://doi.org/10.1080/23808985.2022.2064324

Nueva, M. G. C. (2019). A Literature Review on the Current Technology in Education: An Examination of Teachers Use of Technology and Its Association to Digital Inequality in School. *DLSU Arts Congress*, 1–8. https://www.dlsu.edu.ph/wp-content/uploads/pdf/conferences/arts-congress-proceedings/2019/CP-04.pdf

Oswald, T. K., Rumbold, A. R., Kedzior, S. G. E., & Moore, V. M. (2020). Psychological impacts of "screen time" and "green time" for children and adolescents: A systematic scoping review. *PloS One*, *15*(9), e0237725. https://doi.org/10.1371/journal.pone.0237725

Pérez Sedeño, E. (2021). Gender: The Missing Factor in STS. In D. G. Johnson & J. M. Wetmore (Eds.), *Inside technology. Technology and society: Building our sociotechnical future* (Second edition, pp. 173–184). The MIT Press.

Prensky, M. (2003). *Digital game-based learning* (Vol. 1). McGraw-Hill.

Pirker, J., & Dengel, A. (2021). The Potential of 360° Virtual Reality Videos and Real VR for Education-A Literature Review. *IEEE Computer Graphics and Applications*, *41*(4), 76–89. https://doi.org/10.1109/MCG.2021.3067999

Robledo, D. A. R., & Prudente, M. S. (2022). "A Virtual Fieldtrip": Effects of Google Earth Learning Activities (GELA) on Students' Environmental Awareness and Environmental Attitudes. In *ACM Digital Library, 2022 13th International Conference on E-Education, E-Business, E-Management, and E-Learning (IC4E)* (pp. 1–8). Association for Computing Machinery. https://doi.org/10.1145/3514262.3514293

Roelofsen, M., & Carter-White, R. (2022). Virtual reality as a spatial prompt in geography learning and teaching. *Geographical Research*, *60*(4), 625–636. https://doi.org/10.1111/1745-5871.12551

Rogelj, B., Resnik Planinc, T., Repe, B., & Ilc Klun, M. (2024). Education for sustainable mobility in Slovenia: Using gamification to influence the travel habits of children. *European Journal of Geography*, *15*(2), 81–93. https://doi.org/10.48088/ejg.b.rog.15.2.081.093

Ruberto, T., Mead, C., Semken, S., Bruce, G., Buxner, S., & Anbar, A. D. (2017, October 22). *Contrasting, Complementary Learning Outcomes of In-Person and Virtual Field-Based Geoscience Instruction at Grand Canyon National Park.* The Geological Society of America. GSA Annual Meeting, Seattle. https://doi.org/10.1130/abs/2017AM-306229

Salsabila, T., Putra, A. K., & Matos, T. (2022). Mobile Virtual Field Trip and Geography Education: Potential Exploration of Complex Problem Solving and Spatial Intelligence Capabilities. *International Journal of Interactive Mobile Technologies (IJIM)*, *16*(24), 21–31. https://doi.org/10.3991/ijim.v16i24.36157

Siegmund, A., Michel, U., Forkel-Schubert, J., & Jahn, M. (2013). Digitale Medien in der BNE aus Sicht der Geographie. In U. Michel, A. Siegmund, M. Ehlers, A. Bittner, & M. Jahn (Eds.), *Digitale Medien in der Bildung für nachhaltige Entwicklung: Potenziale und Grenzen* (pp. 16–24). Oekom Verlag.

Stumpf, R. J., Douglass, J., & Dorn, R. I. (2008). Learning Desert Geomorphology Virtually versus in the Field. *Journal of Geography in Higher Education*, *32*(3), 387–399. https://doi.org/10.1080/03098260802221140

Svenningsson, J., Höst, G., Hultén, M., & Hallström, J. (2022). Students' attitudes toward technology: Exploring the relationship among affective, cognitive and behavioral components of the attitude construct. *International Journal of Technology and Design Education*, 32(3), 1531–1551. https://doi.org/10.1007/s10798-021-09657-7

Verbeek, P.-P. (2024). *What different kinds of human-technology-world relations exist? Peter-Paul Verbeek explains two dimensions of technological mediation*. https://www.futurelearn.com/info/courses/philosophy-of-technology/0/steps/26321

Virvou, M., Katsionis, G., & Manos, K. (2005). Combining Software Games with Education: Evaluation of its Educational Effectiveness. *Educational Technology & Society*, *8*(2), 54–65. https://www.jstor.org/stable/pdf/jeductechsoci.8.2.54.pdf?refreqid=excelsior%3A9b0148de40c4c8585bb1cd7c2f46f3bb&ab_segments=&origin=&acceptTC=1

Wagenmakers, E.-J. (2021). *JASP* (Version 0.14.1) [Computer software]. JASP Team. https://jasp-stats.org/

Wang, K., Liu, P., Zhang, J., Zhong, J., Luo, X., Huang, J., & Zheng, Y. (2023). Effects of Digital Game-Based Learning on Students' Cyber Wellness Literacy, Learning Motivations, and Engagement. *Sustainability*, *15*(7), 5716. https://doi.org/10.3390/su15075716

Welledits, V., Schmidkonz, C., & Kraft, P. (2020). *Digital Detox im Arbeitsleben: Methoden und Empfehlungen für einen gesunden Einsatz von Technologien* (1st ed. 2020). *essentials*. Springer Fachmedien Wiesbaden; Springer.

Wood, B., Rea, M. S., Plitnick, B., & Figueiro, M. G. (2013). Light level and duration of exposure determine the impact of self-luminous tablets on melatonin suppression. *Applied Ergonomics*, *44*(2), 237–240. https://doi.org/10.1016/j.apergo.2012.07.008

Zeuss, D., Bald, L., Gottwald, J., Becker, M., Bellafkir, H., Bendix, J., Bengel, P., Beumer, L. T., Brandl, R., Brändle, M., Dahlke, S., Farwig, N., Freisleben, B., Friess, N., Heidrich, L., Heuer, S., Höchst, S.,Holzmann, H., Lampe, P., Leberecht, M., Lindner, K., Masello, J. F., Möglich, J. M., Mühling, M., Müller, T., Noskov, A., Opgenoorth, L., Peter, C., Quillfeldt, P., Rösner, S., Royauté, R., Mestre-Runge, R., Schabo, D., Schneider, D., Seeger, B., Shayle, E., Steinmetz, R., Tafo, P., Vogelbacher, M., Wöllauer, S., Younis, S., Zobel, J., & Nauss, T. (2024). Nature 4.0: a networked sensor system for integrated biodiversity monitoring. *Global Change Biology*, *30*(1), e17056. https://doi.org/10.1111/gcb.17056

Zhao, J., La Femina, P., Carr, J., Sajjadi, P., Wallgrün, J. O., & Klippel, A. (2020). Learning in the Field: Comparison of Desktop, Immersive Virtual Reality, and Actual Field Trips for Place-Based STEM Education. In *2020 IEEE Conference on Virtual Reality and 3D User Interfaces* (pp. 893–902). IEEE. https://doi.org/10.1109/VR46266.2020.00012

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