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Sustainable environmental education using virtual reality: A module for improving environmental citizenship competences in secondary schools

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Abstract

Sustainable environmental education (SEE) can develop global citizens. However, environmental education in schools does not develop environmental citizenship (EC). Virtual reality (VR) could provide authentic immersive experiences to evoke emotions for positive action for EC. A SEE module, designed to include VR experiences, was evaluated at a secondary school to determine if it could improve students' EC. A quasi-experimental single-group pre-test post-test design was conducted with 30 students, followed by focus group interviews with the students. The findings indicated the module was effective in improving EC scores. Analysis of interview transcripts indicated students were engaged and motivated to learn with VR and improved in EC competences. However, the future actions for EC were limited to individual actions and not community-based actions. Although there was some potential in the SEE module, some improvements are needed. Future studies could investigate strategies for making students agents of change in the community.

Keywords: sustainable environmental education, environmental education, environmental citizenship, secondary school science

INTRODUCTION

Sustainable environmental education (SEE) is needed to develop responsible global citizens who are able to act in ensuring the sustainability of the environment (Estrada-Vidal & Tójar-Hurtado, 2017). The world faces an environmental crisis from the effects of climate change. Extensive deforestation and pollution have impacted the health, social relations, economy and ecology of many communities, and especially the most vulnerable (Miyamoto et al., 2014; UNICEF Malaysia, 2021). Although environmental education (EE) has been implemented in many countries, the focus is more on personal action, which is an individualistic approach for environmental protection and conservation of resources (Hadjichambis & Reis, 2020; Parra et al., 2020; Stern, 2000; DeWitt et al., in press). This has resulted in developing citizens who are aware of global environmental issues but are unable to take the necessary actions to resolve these issues (UNDP, UNICEF & EcoKnights, 2020). Hence, a more sustainable approach for EE is required (Stern, 2000). SEE includes community engagement to develop citizens who are able to take collective action in solving economic, environmental and social problems (Marzo et al., 2023; Weil, 2021). Hence, SEE should include environmental citizenship (EC) to promote individuals as responsible global citizens who can actively participate in both public and personal spaces and take collective action and responsibility for the environment (Parra et al., 2020).

The integration of EE in the school science curricula seems to be unsustainable as not only do students lack environmental awareness and knowledge but they do not seem to take positive action (Robelia & Murphy, 2012; Sukma et al., 2020). This seemingly lack of interest among students could be attributed to ineffective approaches for teaching EE. There does not seem to be many EE training programs available for Malaysian teachers (Esa, 2010; Lateh & Muniandy, 2010). As a result, traditional teaching methods have been applied,

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Contribution to the literature

- An SEE module designed based on place-based education, the socio-scientific inquiry for solving problems and the first principles of instruction, was shown to be effective for improving environmental citizenship scores among students.
- Virtual reality (VR) technologies used in the SEE module enabled place-based education within the classroom and allowed students to explore concepts in hazardous situations and interact to discover authentic issues in different environments.
- The use of VR engaged and motivated students to learn and resulted in developing EC competences. Although students could share the 3D virtual environments they created, their actions were more individualistic in nature.

and no significant change in students' behavior was observed (Sukma et al., 2020). Teachers do not seem to be aware of the specialized pedagogies for teaching EE and complain of insufficient resources (Paraskeva-Hadjichambi et al., 2020). Hence, implementing SEE will require providing the resources for developing citizens with skills for responsible pro-environmental behavior to be agents of change in their community in the future (DeWitt et al., in press).

For this purpose, a SEE module was designed to develop knowledge and skills to be environmental citizens by providing meaningful and authentic opportunities for learning using an immersive technology. VR can be used to evoke emotions and encourage positive action when used for learning (DeWitt & Adams, 2020; DeWitt et al., 2022). Hence, in the SEE module, VR technologies was used to provide a variety of settings to evoke learners' emotions such as empathy and promote positive action. This study investigates the effectiveness of the SEE module for developing EC among students.

Sustainable Environmental Education

Ensuring sustainability means an interdisciplinary collaborative approach is needed, which combines multiple subjects such as geography, psychology and environmental science to achieve environmental protection, a balanced economic development and social inclusion (Smederevac-Lalic et al., 2020). Different forms of knowledge, interests and value commitments would be integrated in a participatory approach for knowledge production (Smederevac-Lalic et al., 2020). There are three pillars for sustainability: environmental, social and economic sustainability; and one of the key themes of sustainable development is citizenship sustainability (Hadjichambis & Reis, 2020; United Nations [UN], 2015). Hence, in education for sustainability, EE is integrated with the ecological, social and economic dimensions for developing EC (UNESCO, 2009). An EC approach is suitable for developing global citizens who need to acquire different forms of knowledge to make value commitments and informed decisions.

EC requires individuals to act for responsible pro-environmental behavior, and be change agents at all levels of society, both locally and globally (European Network for Environmental Citizenship, 2018). EC is situated within citizenship theory and reflects the understanding that active involvement in achieving the aspirations of sustainable development and promoting societies committed to sustainably is the responsibility of each citizen (Hadjichambis & Reis, 2020). Global citizens may act as individuals, or collectively as a group, to solve contemporary environmental problems and prevent future environmental problems from occurring (Hadjichambis & Reis, 2020). In order to be proactive and effect change, there needs to be a transformation which may involve a change of values, beliefs, attitudes and behavior as the individual makes a change and recognize themselves as global citizens (Barry, 2006). Hence, it is important to determine if the SEE module could be used to develop EC among students.

Climate change is a significant global environmental problem which requires citizens to take proactive action in order to be sustainable (Stern, 2011). As an environmental citizen, one would need to exhibit environmentally significant behaviors to address the problem of climate change. Behaviors could include activism such as participation in public events (e.g., participate in demonstrations and campaigns on climate change), non-activism in public spaces where public policies related to the environment are supported (e.g., willingness to pay higher taxes and voting for protection) and personal lifestyles in private spaces (e.g., choices related to the purchase, use and disposal of goods, as well as green consumerism) (Stern, 2000). Hence, EC requires students to be active in both the public and private spaces, which can only result from having positive values and beliefs.

In order to cultivate environmentally significant behaviors for sustainability, EC should be encouraged in schools at an early age. Although EE has been a part of science education in schools, it is narrowly focused on environmental protection and conservation of resources (Parra et al., 2020), as it is individualistic nature and encourages personal action (Hadjichambis & Reis, 2020). EE has not encouraged the development of responsible environmental citizens. This is because in EE, only the change in personal lifestyles and choices, and not action for the community, are emphasized (Stern, 2000). The competencies associated with EC are measured in the cognitive and affective domain as well as in the actions in private and public settings, both now and in the future (Hadjichambis & Paraskeva-Hadjichambi, 2020). This would include the knowledge, conceptions, and skills, as well as attitudes and values, and the engagement in actions related to EE now and in the future (Hadjichambis & Paraskeva-Hadjichambi, 2020b).

Although EC should be encouraged in schools, teachers may have difficulty teaching EC for SEE. Firstly, teachers require interdisciplinary expertise in subjects such as biology, geography, economy and politics. Further, most teachers of EE are not specialists and perceived that they lack training for teaching SEE (Behrendt & Franklin, 2014). This is evident in Malaysia as teachers have insufficient training in EE (Esa, 2010; Lateh & Muniandy, 2010). Finally, EE is only integrated in one subject, namely science, and often focuses on the cognitive domain of learning, which is insufficient to bring about transformation in behavior, skills, and attitude among secondary school students (Sukma et al., 2020).

SEE should not be implemented in only the formal settings of the classroom but in a variety of settings. This includes non-formal settings, allowing for voluntary work in or outside school, and at informal settings such as in public events and spaces for campaigns and non-activism demonstrations (Paraskeva-Hadjichambi et al., 2020). However, this requires the teachers to have extensive knowledge in SEE. At the same time, teachers seem to lack the content knowledge for SEE (Kim & Fortner, 2006) and the outdoor knowledge to implement SEE effectively (Borsos et al., 2022; Neville et al., 2023).

There are specialized pedagogies and tools for teaching SEE (Paraskeva-Hadjichambi et al., 2020). However, secondary school teachers may be unaware of pedagogies such as place-based education, civic ecology education, ecojustice pedagogy and action competence, and lack the motivation to implement these pedagogies when teaching (Paraskeva-Hadjichambi et al., 2020). Further, the lack of time for planning and preparing lessons to integrate these specialized pedagogies for SEE is also an issue (Behrendt & Franklin, 2014; Sukma et al., 2020). In addition, teachers may not have resources and instructional materials for teaching SEE (Paraskeva-Hadjichambi et al., 2020). Hence, having a SEE module with resources for students' learning, would be useful.

VR for Learning

VR has been shown to be engaging for students in both the cognitive and affective domain (DeWitt et al., 2022). VR technologies can heighten the sense of presence in a digital environment (DeWitt et al., 2022; Makransky & Lilleholt, 2018) . When learning Chinese as a foreign language at a higher education institute, VR contributed to an increase in intercultural communicative competences among learners, which included having initiative to learn about other cultures and being tolerant towards people from different cultural backgrounds (DeWitt et al., 2022). Students were engaged with the intercultural experience in VR and were motivated to use the technology for learning the language (DeWitt et al., 2022). Learners using VR had an active interest in discovering cultural details in virtual developmental niches and the interactions were virtual affordances to scaffold learning in VR (DeWitt et al., 2022; Shadiev et al., 2018; Sukhoverkhov & Dewitt, 2024). There was a willingness to learn more and be active in discovering new information and cultures.

The use of VR enables learners to experience a sense of presence and immersion in cultural environments and this has provided an authentic cultural experience (Shadiev et al., 2020). VR can provide a much higher level of immersion and control than other media such as graphics or videos as learners experience learning in developmental niches (Sukhoverkhov & Dewitt, 2024). Learners have a sense of autonomy in their learning as they can explore on their own (Makransky & Lilleholt, 2018). Some studies indicate that VR with peer assessment had higher learning effectiveness and promotes higher self-efficacy and critical thinking tendencies (Liu et al., 2019). As such, the SEE module would include VR resources and peer learning to develop EC for secondary school students to value the environment.

Although VR has potential for improving learning outcomes for SEE, there are potential issues which needs to be considered. Students may be distracted when using VR, especially as it has been associated with experiences in gaming (Bower & Sturman, 2015; Dávideková et al., 2017). The lack of familiarity with the interface in VR as well as lack of resources (e.g., insufficient devices and low internet bandwidth), may limit the use of VR (Bower et al., 2020). In addition, the lack of support when faced with technical problems in using VR could hinder the use of this technology (Bower & Sturman, 2015). Even more concerning is the health issues related to the use of VR such as dizziness, eyestrain and in more severe cases, cyber sickness and epileptic fits among users (Bower et al., 2020; Southgate, 2018).

VR is useful for enabling the pedagogies for SEE as it provides experiential learning using place-based education and a culturally relevant pedagogy. Students can be transported to different environments and different settings in VR to explore new environments and suggest solutions to the problems encountered. Hence, VR allows for a socio-scientific inquiry-based learning approach as the learner explores within his environment and discovers the appropriate course of action to be taken for change. However, provisions will also be needed to ensure that students can explore in a safe and secure environment, without encountering any issues. Hence, the SEE module would consider the challenges users might face when using VR in the classroom.

VR for Place-Based Education for SEE in Secondary Schools

There are a variety of instructional methods for sustainable education such as outdoor education and fieldwork, experimental, interactive and experiential learning (Jeronen et al., 2017). For developing EC, pedagogies such as place-based education have been suggested (Paraskeva-Hadjichambi et al., 2020).

Place-based education is frequently used to cultivate EC (Bauer et al., 2020; Paraskeva-Hadjichambi et al., 2020). In order to develop a favorable or unfavorable attitude towards an environment, it is always better to be at the place as this provides the intensity and centrality of the attitudes (Bauer et al., 2020). This means bringing students to the specific places within the community to investigate problems which needs to be solved. It has been shown that having an open and active classroom, with lots of interactivity, can promote civic attitudes (European Commission: Joint Research Centre et al. 2018). Hence, place-based pedagogies which involves engagement with the community is more effective in developing EC as students need to abide with the social norms of the community (Goldman et al., 2020).

In place-based education, the emphasis is on a learning ecology where the interactions between the physical, social, and cultural contexts are important for learning (Paraskeva-Hadjichambi et al., 2020). Hence, learning takes place in the both the formal classrooms as well as during non-formal and informal sessions. Hence, learning ecosystems need to be designed for learning to be extended to the home for informal learning, for visits to other places of interest such as the museum or science center for non-formal learning (Paraskeva-Hadjichambi et al., 2020).

Organizing visits to places for large groups of students could be difficult due to the resources required. As the lack of time for planning and integrating these pedagogies is a difficulty for teachers (Behrendt & Franklin, 2014; Sukma et al., 2020), it is suggested that virtual visits be employed using VR. VR could extend the experience and ensure that the momentum for learning is maintained as students have the opportunity to experience the elements they were discussing in the formal classroom (Paraskeva-Hadjichambi et al., 2020).

With VR, students can teleport immediately to the environments being discussed and be provided with ‘first-order experiences’ where they can construct their own knowledge as they view and interact in the places in the community (Bower et al., 2020). The affordance of VR is that the learner is able to experience multiple perspectives as there is sensory immersion, actional immersion, and symbolic emersion in the virtual environment, which can allow developing new perspectives (Bower et al., 2020). VR can enable users to enhance place-based education by making it a more practical option for teachers to implement. In addition, the possibility for using VR to evoke emotions for affecting change, makes it a viable possibility for use in developing EC (DeWitt et al., 2022).

After the virtual experience in VR, students can suggest the problems while they were immersed with in the environment. Problem-based learning can be used to discuss the solution to the problems, as students interact in the local context and critically examine issues which may be related to local authority and power, ethnicity and discuss alternative ways of resolving the problems (Tuck et al., 2014). Hence, place-based education provides the opportunity for learning to be in the environment and to critically analyze the contexts in order to determine the best actions for sustaining social and environmental practices (Meichtry & Smith, 2007). VR enables place-based education by bring the places to the classroom. However, it is not known if this strategy of teaching could develop EC among secondary school students.

MATERIALS AND METHODS

Study Design

In this exploratory implementation study, the SEE module was implemented over 5 weeks with a group of 30 students. The effectiveness of the SEE module for developing students’ EC was determined using a single group pretest post-test quasi-experimental design to investigate if there was an increase in the EC scores after the implementation of the SEE module. Students’ EC level before and after implementation was determined using a questionnaire. Focus group interviews were conducted and observations of the virtual worlds the students created in the *CoSpaces Edu* app was done to verify the findings and to investigate students’ perceptions of their learning with the SEE module.

The module was implemented at a selected secondary school in an urban area, which had a high level of technology use, and where the management and students were willing to participate in the study. As the study was conducted during the lockdown period during the COVID-19 pandemic, classes had to be conducted online, and safety precautions had to be taken during the face-to-face sessions. Only one intact class were randomly selected from eight form 2 classes at the school. The 30 students were selected from the volunteers in the class.

Instruments

The environmental citizenship questionnaire (ECQ), which was designed based on the education for

Table 1. Reliability statistics for the nine factors of EC

Areas	Factors	n	Range of Likert scale	Cronbach's alpha	
Past and present actions	Past actions as ECn	6	1 = no, 2 = yes, within 6 months, 3 = yes, more than 6 months, 4 = yes, more than 1 year	.895	.895
Competences	Knowledge for ECn	11	1 = not at all, 2 = small extent, 3 = moderate extend, 4 = large extent	.914	.941
	Conceptions for ECn	12	1 = not important, 2 = not very important, 3 = quite important, 4 = very important	.853	
	Skills of ECn	6	1 = not at all, 2 = not very well, 3 = fairly well, 4 = very well	.875	
	Attitudes of ECn	8	1 = very much disagree, 2 = disagree, 3 = agree, 4 = very much agree	.909	
	Values of ECn	15	1 = not important, 2 = slightly important, 3 = important, 4 = most important	.918	
Future actions	Future actions inside school	4	1 = not at all likely, 2 = not very likely, 3 = quite likely, 4 = very likely	.853	.906
	Future actions outside school	11	1 = certainly not do, 2 = probably not do, 3 = probably do, 4 = certainly do	.904	
	Agents of change	3	1 = certainly not do, 2 = probably not do, 3 = probably do, 4 = certainly do	.817	
		76		.943	

Note. n: Number of items

environmental citizenship framework in the European network for environmental citizenship (Hadjichambis & Paraskeva-Hadjichambi, 2020). The framework provided a means to investigate the EC activities in the past and present, competences, and the intention to act. The questionnaire employed a 4-point Likert scale and consisted of 76 questions in these aspects:

1. Activities as environmental citizen (ECn): Past and present
2. Competences of an environmental citizen (ECn)
3. Intention to act in the future as an environmental citizen (ECn)

In this study, there was slight modifications to the ECQ to suit the context, but these were maintained to a minimum to ensure accuracy of the measures. The modified ECQ was validated by two experts with more than five years teaching experience in EE. The questionnaire is reliable with the overall Cronbach's alpha of .943, indicating it was highly acceptable in all factors (Nunnally, 1978). The scales and the reliability of the factors are shown in **Table 1**.

The instrument for the focus group interview was an interview protocol to gather students' opinions on their learning with the SEE module for EC. For this purpose, open ended questions were asked to explore the students' future intentions and perceptions. In addition, the virtual worlds that students created were evaluated using a checklist to determine whether students exhibited EC in their work. These instruments (interview protocol and observation checklist) were validated by experts in EE and piloted before the study to determine if it could be used in this context.

The Sustainable Environmental Education Module

The SEE module, designed from input among a panel of experts, aimed to develop students' EC. This meant they would acquire global, critical, and reflective awareness of the social, economic, cultural, and environmental contexts among students so that they will take an ethical position and act based on the principles of sustainable development.

The SEE module was developed based on theories of learning and instruction related to EE and EC. Place-based education is focused on the environment, and a culturally relevant pedagogy which affirms the students' cultural identity while developing critical perspectives that challenges inequities are suitable pedagogies for SEE (Ladson-Billings, 1995). These pedagogies could cultivate environmentally significant behaviors for sustainability to make students aware of their actions and critically reflect on the consequences of their actions to promote change. Culturally relevant pedagogy focuses not only on academic success and cultural competence, but also on sociopolitical consciousness (Ladson-Billings, 1995) which is suitable for cultivating EC. A sense of belonging is cultivated among students who are then encouraged to act for the sustainability of their environment (Harrison & Skrebneva, 2020).

Although inquiry-based learning approaches have been used in science education, a socio-scientific inquiry-based learning could be more relevant for SEE to critically appraise social and political issues. Socio-scientific inquiry-based learning is engaging as students pose inquiry questions which are relevant locally and personally (Amos et al., 2020). It can promote informed and responsible action in relation to socio-environmental issues (Ariza et al., 2021). This strategy draws upon three interacting pillars: socio-scientific

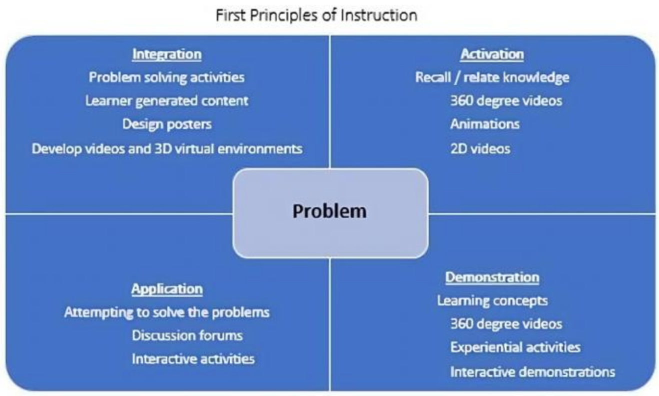

Figure 1. The framework for the design of the SEE module (Tan, 2024)

issues, inquiry-based science education and citizenship education (Levinson, 2018).

The SEE module was designed to cover five units with four to six lessons in each unit:

(1) water pollution,

(2) air pollution,

(3) waste disposal,

(4) climate change, and

(5) a case study–fast fashion and the environment.

There was a total of 22 lessons for the module which was developed based on experts' consensus for place-based learning for sustainable education (Sobel, 2004). Virtual environments such as 360-degree videos and simulations in VR, as well as 2-dimensional (2D) videos were employed as suggested by experts to be suitable resources for experiential learning for place-based learning.

The core of SEE is the socio-scientific inquiry-based learning which focuses on solving problems for EC (Febriasari & Supriatna, 2017; Kricsfalusy et al., 2018; Kuvac & Koc, 2018). Hence, the first principles of Instruction is a suitable instructional framework for the SEE module. In the process of solving the problem, the student needs to be involved in several instructional phases: activation, demonstration, application, and integration of knowledge (Merrill, 1994). The framework for the design of the SEE module is shown in **Figure 1**.

In the activation phase, knowledge is activated when appropriate media and tasks are provided to relate to prior experience and inform students the objective of the lesson (Heinich et al., 2002; Morrison et al., 2012). In socio-scientific inquiry-based learning, the first step is asking authentic questions about controversial issues arising from the impact of science and technology in society (Levinson, 2018). In this phase, VR with 360-degree videos was used for place-based education as students are immersed in polluted rivers and cities such as the Ganga River and Delhi and witness irresponsible waste disposal for urban waste management.

Learning in the demonstration phase is promoted when examples and non-examples are shown to learn concepts, and visualizations to learn processes and modelling of appropriate behavior (Merrill, 2002). The possible causes of an issue, such as water pollution, is investigated and information is gathered to uncover these causes before appropriate action is suggested and steps taken to formulate solutions and enact change (Knippels et al., 2017). VR with 360-degree videos is used to show best practices and processes, as well as worst case scenarios, and was supplemented with videos in 2D format, e.g., "beat plastic pollution" for water pollution. There would be questions to answer based on the videos.

In the application phase, practice and feedback are important for students to predict the consequences of their actions (Merrill, 2002). In this phase, problem solving activities which emphasize feedback and coaching, are important. In addressing climate change, students were asked to compare environments in VR with 360-degree videos of a city and the wilderness and asked to discuss the differences in these environments and the potential causes and future effects of climate change on the existing environment. They reported their ideas in an online discussion forum. In a lesson on Water Pollution, students had to identify the possible causes of the "water cuts" in their community, which a possible cause was environmental pollution. A "home water audit" for water consumption in their family, had to be undertaken and possible solutions in protecting the water sources in the community, proposed. Activities such as the home water audit in this phase required students to collect data and make analyses, before making a conscious decision on the need for change.

Finally, for the integration phase, students are provided opportunities to show the skills and behavior they developed. Students were required to solve problems in the local and global situations, and to act in ensuring sustainable solutions. In addition, activities for student-generated content where students design posters and videos to inform the community of strategies to ensure a more sustainable future is incorporated in the module. The posters could be disseminated through social media. Students designing their own 3D virtual environments in *CoSpaces Edu*, an application for developing and sharing the virtual environments in VR, was also used for students to share ideas and solutions in maintaining a better and more sustainable world.

The SEE module incorporating socio-scientific inquiry-based learning for experiential and place-based learning using the First Principles of Instruction was implemented with the students in the context of the study to evaluate if it could cultivate EC.

Table 2. Normality test

	Kolmogorov-Smirnov[a]			Shapiro-Wilk		
	Statistic	df	Sig.	Statistic	df	Sig.
Pre-test	.105	30	.200*	.982	30	.865
Post-test	.086	30	.200*	.975	30	.672

Note. [a]Lilliefors significance correction & *This is a lower bound of the true significance

Data Analysis

In order to determine the effectiveness of the SEE module on students' EC scores, data was collected and analyzed to test the following null hypotheses:

H_0. There is no significant difference between the median in the pre-test and post-test scores following the implementation of the SEE module.

Since the sample size was small (n = 30), determining the distribution of the variable was important for selection of the appropriate statistical method. The Shapiro-Wilk test for the pretest scores (W = 0.982, p = .865) and post test scores (W = 0.975, p = .672) did not show evidence of non-normality, as p>0.05 (see **Table 2**).

The Wilcoxon signed-rank test was used to compare the medians of the pretest and post-test scores to determine the effectiveness of the module on the level of student's EC. The following assumptions were made. Firstly, the dependent variable is ordinal as it was a Likert scale, and secondly, the independent variable is of two categorical matched pairs: pretest and posttest. Finally, the distribution of differences of scores between the two related groups are symmetrical.

As for the focus group interviews, the interviews with the students were audio-recorded and then transcribed. The transcripts of the interviews were coded and analyzed thematically to determine whether there were elements of EC. The VR environments which the students created on *CoSpaces Edu* were evaluated to investigate whether there were elements of EC in the virtual environments. The emerging themes were classified and reported.

RESULTS

The Effectiveness of the SEE Module

In order to determine the effectiveness of the SEE module, the Wilcoxon signed ranks test was used. The two-sample paired data used are part of the same population and the null hypothesis is that the median of the population of differences between the paired data is zero (King & Eckersley, 2019). The Wilcoxon signed-rank test showed that there was a significant difference between the pretest and posttest scores (Z = -4.454, p < .000). The results indicated that posttest ranks were significantly higher than pretest ranks (see **Table 3**, **Table 4**, and **Table 5**). Next, the effect size was calculated by dividing the absolute standardized test statistic z by the square root of the number pairs $= \frac{Z}{\sqrt{n}} = \frac{4.445}{\sqrt{30}} = 0.812$. According to Cohen's (1988) classification of effect sizes, the effect size of 0.812 is sufficiently large.

The results indicated that post-test ranks were significantly higher than pre-test ranks, and post-test was preferred and received significantly more favorable rankings than pre-test. Hence, there was a significant gain in the students' EC scores after using the SEE module, which indicates that the SEE module was effective for improving students EC scores.

VR for EC in the SEE Module

The findings of the focus group interviews provided more details to investigate the development of EC. Several themes emerged to indicate that students' competences improved. This was because the resources in VR allowed students to explore concepts and hazardous situations, interact to discover authentic issues in different environments and be engaged and motivated while learning. This could result in positive action to act as an environmental citizen as students were interested to create the VR environments.

EC competence

The following themes emerged related to EC competence.

Exploration in VR to learn concepts of EE: The SEE module promoted exploration and inquiry as students interacted with the virtual environments, thus improving their understanding of science concepts related to EE.

> "Sometimes students need to see and visualize a concept in order to fully understand it instead of just staring at a 2D picture. With VR, students can interact and explore how a concept works" (G6 student D1).

Exploration of hazardous situations in VR to develop values of EC: The use of VR enabled students to be in environments which were physically impossible to access. Polluted areas and dangerous sites could be explored from the safety of the classroom in VR.

> "… in real life, we are sometimes restricted of going to dangerous places in the area (examples like, the actual excavation sites). In VR however, we'd be able to virtually experience without getting harmed in the process" (G5 student X).

Exploration of authentic issues in different environments to develop attitudes of EC: The SEE module had enabled environmental issues to be portrayed in a realistic manner, and this engaged the students. The immersive nature of VR environments

Table 3. Hypothesis test summary for environmental citizenship

	Null hypothesis	Test	Sig.	Decision
1	The median of difference between pretest and posttest equals 0	Related samples Wilcoxon signed rank test	.000	Reject the null hypothesis

Note. Asymptotic significances are displayed, the significance level is .05, & effect size of 0.812

Table 4. Wilcoxon signed rank test for the pre- and post-test for environmental citizenship

		N	Mean rank	Sum of ranks
Post-/Pre-test	Negative ranks	2[a]	8.00	16.00
	Positive ranks	28[b]	16.04	449.00
	Ties	0[c]		
	Total	30		

Note. [a]Post-test < pre-test, [b]Post-test > pre-test, & [c]Post-test = pre-test

Table 5. Statistics for pre- and post-test for environmental citizenship

	Post-/pre-test
Z	-4.454
Asymptotic Sig. (2-tailed)	.000

Note. [a]Wilcoxon signed rank test & [b]Based on negative ranks

could have attributed to the realistic portrayal of the environments.

> "VR had done many things that are impossible for reality. By using VR, we can have a better view of the environmental problem that we are facing" (G4 student T).

> "I will prefer VR experience because it is more interesting. This can make me not to feel bored easily and it is more realistic compared to pictures in textbook so we can learn it more easily (G2 student I).

Engagement for learning: Students were engaged with the VR content which improved learning.

> "I will prefer VR experience because it is more interesting. This can make me not feel bored easily and it is more realistic compared to pictures in textbook so we can learn it more easily (G2 student I).

One student agreed that VR has made education more engaging because he spent more time using the VR resources.

> "The introduction of VR has made it possible to experience education in more immersive and engaging ways" (G2 student J).

Most of the students agreed that they were motivated to learn and participate in the learning activities as they persisted until the end of the lesson, making their learning more effective. This was attributed to the interesting VR experience:

> "... I think the VR experience is more effective because it is interesting, and I can finish the lesson all by myself without getting bored" (G4 student S)

The implementation of the SEE module was during the COVID-19 pandemic and classes had to be conducted online some days of the week. Although there were low levels of engagement recorded in most of the online classes, students reported that learning with the SEE module was not a problem due to the engaging nature of the content and the technology used:

> "Especially in this pandemic time, online classes have many problems such as less interactivity, the student might not pay attention. By using VR some of the problems can be settled" (G4 student T).

Intention to act in the future as an ECn

The following themes emerged related to intention to act as an environmental citizen.

EC behavior in the future: The immersive nature of VR ensures the student experiences authentic situations which would appeal to their emotions and encourage them to act as environmental citizens. The perception of being physically present in a virtual world, is created by the surroundings which was realistic for them. They indicated positive action they would take to reduce pollution, for example:

> "… you use a VR headset you can save petrol money and pollution of air. Personally, I now prefer VR over going there literally this is way more convenient and accessible" (G6 student C1).

Student-generated content for environmental action and agents of change: Solving problems could promote informed and responsible action in relation to socio-environmental issues (Ariza et al., 2021). In the SEE module, there were some problem-solving activities where students had to develop content. As an example, in the lesson on air pollution at home, students were required to suggest actions which could reduce air pollution at home and to share their thoughts with their peers in a virtual environment using the *CoSpaces Edu* application. Students had to visualize human activities which contributed to increase in air pollution and suggest the solutions to reduce the problem. The 3D

Figure 2. Screen capture of a 3D virtual environment creation by student B (Tan, 2024)

Figure 3. Screen capture of a 3D virtual environment creation by student C (Tan, 2024)

virtual environments students developed were shared with their peers.

The students were engaged in the activity and could successfully generate 3D virtual environments where suggestions to reduce air pollution were given. This was evidenced in the conversations captured in the virtual environments (see **Figure 2** and **Figure 3**).

The SEE module seemed to be effective for improving secondary students' competences as environmental citizens. This was because students' involvement in activities as environmental citizens, were increased and the created virtual environments for sharing with their peers.

Students' perceptions of the SEE module

The students perceived that the SEE module enabled them to have autonomy in learning. However, some students reported that they were distracted when learning. There were also other challenges such as health issues due to VR sickness, the cost of the devices and the low bandwidth for connectivity.

Autonomy in learning: The SEE module enabled students' autonomy in learning as students could manage their learning independently. The technology tools allowed students to assert control over their learning, thus ensuring a personalized learning experience (Grant & Basye, 2014). This was mainly attributed to the VR technology as the students could control their movement in the virtual world and improve their learning experiences.

> "Learning either by textbook or VR is both learning, the only difference between is the method of learning... I prefer VR as I do not need to face a dull thick textbook for the entire morning and can control learning at my own pace" (G5 student W).

Distractions in learning: Some students reported that they were distracted when learning with the SEE module as they were too immersed in the VR environments. They did not focus on the content that was shown and were distracted by the virtual surroundings. Further, some students were worried that other students were using their mobile phones (which were used to access the VR environments) for purposes other than learning.

> "… I think VR learning would make people lazy, and they would be easily distracted because they are too immersed in this universe. They would choose this as a form of escapism and wouldn't want to leave it. This could be harmful to the individual's psychological well-being. They could also misuse it and that defeats the purpose of VR learning" (G6 student C1).

Health issues: Some students reported that VR technology caused discomfort.

> "VR can cause headaches, eye strain, dizziness and nausea when is used too much" (G5 student V).

Other students had also reported that the prolonged use of VR had led to symptoms such as nausea, dizziness and sweating.

Cost: The students perceived that the VR device was expensive, depending on the type and specifications. Students reported that they could not afford the cost of the VR headset with high specifications.

> "… VR headset is also very expensive as we need a good device to get it full potential. Nowadays VR are equipped with high processing graphic cards and its very expensive ..." (G2 student J).

Internet connectivity: The internet connectivity was a problem at the school as there was limited bandwidth available.

> "… We need Wi-Fi to use VR, but we can't connect our school Wi-Fi" (G4 student T).

DISCUSSION

The SEE module was effective as students' EC scores in the posttest seemed to significantly improve. The analysis of the transcripts during the focus group interviews indicated that the discussion was more on the competences and perception of the resources in the SEE module rather than on the intention to act as environmental citizens. Students did not show evidence of their activities as environmental citizens in the past nor in the present, which was similar to previous studies where students lack knowledge about the positive action which needs to be taken (Robelia & Murphy, 2012; Sukma et al., 2020). However, the effects of the SEE module might be gradual. Hence, a longitudinal study to investigate if there were changes in students' EC and whether they would take positive action in the future, and factors which inhibit this intention.

The second aspect of EC are the competences which include the knowledge, conceptions, skills, attitudes and values related to EE (Hadjichambis & Paraskeva-Hadjichambi, 2020). The students perceived that they improved in knowledge and skills of EC as evidenced from the transcripts. As students were using VR to explore concepts in EE, they could access locations otherwise inaccessible, which were highly polluted or hazardous (Bower et al., 2020). These immersive VR environments were developmental niches for learners to interact and explore with scaffolds for developing their understanding (Sukhoverkhov & Dewitt, 2024).

The SEE module employed VR environments for place-based education. Place-based education emphasizes experiential, community-based, and contextual learning in developing EC, hence ensuring the community is prioritized (Schild, 2016). However during the pandemic, place-based education was not implemented fully. Place-based education highlights the four elements:

(1) the biophysical context of place,

(2) the psychological experience within the space,

(3) the social cultural context to develop and maintain a relationship with the place, and

(4) the political-economic processes that shape the place and peoples' attitudes towards it (Ardoin et al., 2012).

Limitations existed due to time, safety and other logistics (Bauer et al., 2020; Paraskeva-Hadjichambi et al., 2020).

However, in the SEE module, VR was used to transport students to a virtual biophysical place, and the immersive nature provided the psychological experience and social cultural context through scaffolds in developmental niches in the virtual environment (Ardoin et al., 2012; Sukhoverkhov & Dewitt, 2024). Although the psychological experience and socio-cultural relationships could develop the attitudes towards the political-economic processes within the place, there does not seem to be much discussion on this nature in the transcripts of the focus group interviews. Hence, it is not clear whether VR could be effective for encouraging action for political and economic reform in the community and it is suggested that future studies could explore whether place-based education with VR could enable students to act for the good of the community in the future (Stern, 2000).

Attitudes and values related to EE are also competences for EC (Hadjichambis & Paraskeva-Hadjichambi, 2020). The SEE module which used VR for place-based education seems to be effective for developing students' emotions due to the realistic portrayal and immersive nature (Bauer et al., 2020). Engagement with the content is an important factor for learning and students considered the VR experience as interesting and engaging enabling the "study of the place" and were able to spend a longer time "learning in the place" virtually (Granit-Dgani, 2021). However, it is not clear if students achieved the other two dimensions which are "learning from the place" using the unique educational role of the place or "learning for the sake of the place" to champion change for the place as there did not seem to be any evidence of students wanting to affect change (Granit-Dgani, 2021). On the other hand, the engaging and motivating nature of VR was obvious among students and was similar to many studies (Bower et al., 2002). However, this motivation could be due to the novelty of the technology (Bower et al., 2002). Hence, further studies could be implemented to determine if students' motivation would be constant when additional modules were implemented for a longer time.

The third aspect of EC is the intention to act in the future as an environmental citizen. The analysis of the transcripts showed that students did indicate actions they would take in the future, but these actions were more individualistic in nature (Hadjichambis & Reis, 2020). The actions to be taken in public settings and for the community, both now and in the future did not emerge from the data (Hadjichambis & Paraskeva-Hadjichambi, 2020; Stern, 2000). Although, there seemed to be a significant increase in the intention to act in the future from the quantitative data, this was not obvious in the qualitative data. Hence, future iterations of the SEE module could emphasize more on learning for the sake of the place, i.e., for the community, and for political and economic reform.

The SEE module was designed based on Merrill's (1994) first principles of instruction where problem solving was at the heart of the instruction. This is consistent with the socio-scientific inquiry-based learning approach for problem-based learning for EE (Febriasari & Supriatna, 2017; Kricsfalusy et al., 2018; Vasconcelos, 2012). Problem solving activities enabled students to realize the problem in the community and change their behavior or champion a cause related to the community for EE (Brundiers et al., 2010).

VR in the form of 360-degree videos and VR simulations provided motivation for learning (Bower et al., 2020) and developed positive attitudes towards EE (DeWitt et al., 2022). Hence, students' EC was increased as knowledge of concepts, skills, values and beliefs increased through the virtual experiences (Bower, 2020; DeWitt et al., 2022; Hadjichambis & Paraskeva-Hadjichambi, 2020; Shadiev et al., 2020). Similar to previous studies, VR was used for EE (Cho & Park, 2023; Metcalf et al., 2019) as it created a heightened sense of presence in the environment (DeWitt et al., 2022; Makransky & Lilleholt, 2018). Although VR afforded place-based education, enabling the "study of the place" and "learning in the place", effort is needed for "learning for the sake of the place" so as to develop students who would champion change in the community (Granit-Dgani, 2021). Hence, deeper and more intense attitudes are needed for relevant contexts (Bauer et al., 2020; Paraskeva-Hadjichambi et al., 2020). Perhaps a higher fidelity of the immersive nature of VR could promote a sense of belonging for the environment and encourage students to act for the sustainability (Harrison & Skrebneva, 2020).

Although VR provided the realistic environments for development of EC, it was unclear if students would take proactive action in public spaces (Stern, 2000). In the SEE module, students were creators of knowledge as they had to design and share simulations in VR (Yemini et al., 2023). However, in future these simulations could be shared with a wider audience to highlight the issues of specific communities and help solve their problems (Granit-Dgani, 2021). The socio-scientific inquiry-based learning approach where students are posed issues and problems to develop critical perspectives that challenged the inequalities in society could be culturally relevant and effective (Amos et al., 2020; Ladson-Billings, 1995). The problem-solving approach was practical for EE (Febriasari & Supriatna, 2017; Kricsfalusy et al., 2018; Kuvac & Koc, 2018). Hence, more opportunities for students to pose questions and solve problems which were personally relevant and highlighted socio-environmental issues should be encouraged (Amos et al., 2020; Ariza et al., 2021).

CONCLUSIONS

The SEE module, which employed VR for place-based education and socio-scientific inquiry-based learning to solve problems, seemed to have a positive impact on students' EC (Febriasari & Supriatna, 2017; Granit-Dgani, 2021). Students were more aware of the activities and the competences for an environmental citizen. However, the intention to act in the future as an agent of change for the community was only noted in the post test (Brundiers et al., 2010). The students had created virtual simulations to view in VR, and infographics as a part of the activity in the SEE module and shared their products. This could be considered actions for EC in the community. However, students also report challenges such as distractions in the virtual environments, health issues due to VR sickness, the cost of the devices and the low bandwidth for connectivity (Bower, 2020; Chang et al., 2020).

There were some limitations to the study. Firstly, as an exploratory implementation study, only a small sample of 30 students was employed (Hallingberg et al., 2018). The findings are not generalizable to all secondary school students, but it does investigate possibilities of developing EC. Secondly, the improvement in EC scores needed to be verified through other methods. The motivation in participation could have resulted due to the novelty of the technology (VR) and it needs to be determined if these students would continue to act and engage in promoting change in both private and public spaces in the future (Bower et al., 2020). Hence, future longitudinal studies with this cohort of students could be done to investigate whether the EC competences were retained after a period of time.

The SEE module was implemented during the COVID-19 restrictions when interactions in public spaces was not encouraged due to safety concerns. Hence, the results could be different when there is no movement control and community activities are encouraged. Hence, it is suggested that future studies be conducted with a larger group to determine if there it would encourage EC (Paraskeva-Hadjichambi et al., 2020; Stern, 2000), and perhaps with devices better fidelity to investigate if there were any differences the findings. As VR has the potential to evoke emotions, there is a possibility that a SEE module with VR technologies, place-based education and socio-scientific inquiry-based learning can effect change. This is pertinent as the world needs champions for SEE who can address the inequities between communities and try to take action to solve economic, environmental and social problems (Marzo et al., 2023; Weil, 2021).

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REFERENCES

Amos, R., Knippels, M.-C., & Levinson, R. (2020). Socio-scientific inquiry-based learning: Possibilities and challenges for teacher education. In M. Evagorou, J. A. Nielsen, & J. Dillon (Eds.), *Science teacher education for responsible citizenship. Contemporary trends and issues in science education, vol 52* (pp. 41-61). Springer. https://doi.org/10.1007/978-3-030-40229-7_4

Ardoin, N. M., Schuh, J. S., & Gould, R. K. (2012). Exploring the dimensions of place: A confirmatory factor analysis of data from three ecoregional sites. *Environmental Education Research, 18*(5),583-607. https://doi.org/10.1080/13504622.2011.640930

Ariza, M. R., Christodoulou, A., van Harskamp, M., Knippels, M.-C. P. J., Kyza, E. A., Levinson, R., & Agesilaou, A. (2021). Socio-scientific inquiry-based learning as a means toward environmental citizenship. *Sustainability, 13*(20), Article 11509. https://doi.org/10.3390/su132011509

Barry, J. (2006). Resistance is fertile: From environmental to sustainability citizenship. In A. Dobson, & D. Bell (Eds.), *Environmental citizenship* (pp. 21-48). MIT Press.

Bauer, N., Megyesi, B., Halbac-Cotoara-Zamfir, R., & Halbac-Cotoara-Zamfir, C. (2020). Attitudes and environmental citizenship. In A. C. Hadjichambis, P. Reis, D. Paraskeva-Hadjichambi, J. Činčera, J. Boeve-de Pauw, N. Gericke, & M.-C. Knippels (Eds.), *Conceptualizing environmental citizenship for 21st century education. Environmental discourses in science education, vol 4* (pp. 97-111). Springer. https://doi.org/10.1007/978-3-030-20249-1_7

Behrendt, M., & Franklin, T. (2014). A review of research on school field trips and their value in education. *International Journal of Environmental and Science Education, 9*(3), 235-245.

Borsos, É., Banos-González, I., Boric, E., Lyngved Staberg, R., & Fekete, A. B. (2022). Trainee teachers' perceptions of outdoor education. *Environmental Education Research, 28*(10), 1490-1509. https://doi.org/10.1080/13504622.2022.2031901

Bower, M., & Sturman, D. (2015). What are the educational affordances of wearable technologies? *Computers & Education, 88*, 343-353. https://doi.org/10.1016/j.compedu.2015.07.013

Bower, M., DeWitt, D., & Lai, J. W. M. (2020). Reasons associated with preservice teachers' intention to use immersive virtual reality in education. *British Journal of Educational Technology, 51*(6), 2215-2233. https://doi.org/10.1111/bjet.13009

Brundiers, K., Wiek, A., & Redman, C. L. (2010). Real-world learning opportunities in sustainability: From classroom into the real world. *International Journal of Sustainability in Higher Education, 11*(4), 308-324. https://doi.org/10.1108/14676371011077540

Chang, E., Kim, H. T., & Yoo, B. (2020). Virtual reality sickness: A review of causes and measurements. *International Journal of Human-Computer Interaction, 36*(17), 1658-1682. https://doi.org/10.1080/10447318.2020.1778351

Cho, Y., & Park, K. (2023). Designing immersive virtual reality simulation for environmental science education. *Electronics, 12*, 315. https://doi.org/10.3390/electronics12020315

Cohen, J. (1988). *Statistical power analysis for the behavioral sciences* (2nd ed.). Routledge. https://doi.org/10.4324/9780203771587

Dávideková, M., Mjartan, M., & Greguš, M. (2017). Utilization of virtual reality in education of employees in Slovakia. *Procedia Computer Science,* *113*, 253-260. https://doi.org/10.1016/j.procs.2017.08.365

DeWitt, D., & Adams, D. (2020). Virtual reality for evoking emotions: A motivational design for instruction. In D. DeWitt & D. Adams (Eds.), *Innovative Practices of Technology-enhanced Learning*. UPSI.

DeWitt, D., Chan, S. F., & Loban, R. (2022). Virtual reality for developing intercultural communication competence in Mandarin as a Foreign language. *Educational Technology Research and Development, 70*(2), 615-638. https://doi.org/10.1007/s11423-021-10074-9

DeWitt, D., Alias, N., & Tan, W. Y. (in press). Sustainable environmental education: Issues in the implementation for a sustainable future. *Journal Of Issues In Education.*

Esa, N. (2010). Environmental knowledge, attitude and practices of student teachers. *International Research in Geographical and Environmental Education, 19*(1), 39-50. https://doi.org/10.1080/10382040903545534

Estrada-Vidal, L. I., & Tójar-Hurtado, J.-C. (2017). College student knowledge and attitudes related to sustainability education and environmental health. *Procedia-Social and Behavioral Sciences, 237*, 386-392. https://doi.org/10.1016/j.sbspro.2017.02.030

European Commission: Joint Research Centre, Vera-Toscano, E., Blasko, Z., & Dinis da Costa, P. (2018). Civic attitudes and behavioural intentions in the 2016 International Civic and Citizenship Education Study (ICCS)–New evidence for education and training policies in Europe. *Publications Office*. Retrieved September 13, 2024, from https://data.europa.eu/doi/10.2760/218931

European Network for Environmental Citizenship. (2018). *Defining "environmental citizenship"*. Retrieved September 13, 2024, from http://enec-cost.eu/our-approach/enec-environmental-citizenship/

Febriasari, L. K., & Supriatna, N. (2017). Enhance environmental literacy through problem based learning. *Journal of Physics: Conference Series, 895*, Article 012163. https://doi.org/10.1088/1742-6596/895/1/012163

Goldman, D., Hansmann, R., Činčera, J., Radović, V., Telešienė, A., Balžekienė, A., & Vávra, J. (2020). Education for environmental citizenship and responsible environmental behaviour. In A. C. Hadjichambis, P. Reis, D. Paraskeva-Hadjichambi, J. Činčera, J. Boeve-de Pauw, N. Gericke, & M.-C. Knippels (Eds.), *Conceptualizing environmental citizenship for 21st century education. Environmental discourses in science education, vol 4* (pp. 115-137). Springer. https://doi.org/10.1007/978-3-030-20249-1_8

Granit-Dgani, D. (2021). *Paths to place-based education*. The Mofet Institute.

Grant, P., & Basye, D. (2014). *Personalized learning: A guide for engaging students with technology*. ISTE.

Hadjichambis, A. C., & Paraskeva-Hadjichambi, D. (2020). Environmental citizenship questionnaire (ECQ): The development and validation of an evaluation instrument for secondary school students. *Sustainability, 12*(3), Article 821. https://doi.org/10.3390/su12030821

Hadjichambis, A. C., & Reis, P. (2020). Introduction to the conceptualisation of environmental citizenship for twenty-first-century education. In A. C. Hadjichambis, P. Reis, D. Paraskeva-Hadjichambi, J. Činčera, J. Boeve-de Pauw, N. Gericke, & M.-C. Knippels (Eds.), *Conceptualizing environmental citizenship for 21st century education. Environmental discourses in science education, vol 4* (pp. 1-14). Springer. https://doi.org/10.1007/978-3-030-20249-1_1

Hallingberg, B., Turley, R., Segrott, J., Wight, D., Craig, P., Moore, L., Murphy, S., Robling, M., Simpson, S. A., & Moore, G. (2018). Exploratory studies to decide whether and how to proceed with full-scale evaluations of public health interventions: A systematic review of guidance. *Pilot and Feasibility Studies, 4*, Article 104. https://doi.org/10.1186/s40814-018-0290-8

Harrison, N., & Skrebneva, I. (2020). Country as pedagogical: Enacting an Australian foundation for culturally responsive pedagogy. *Journal of Curriculum Studies, 52*(1), 15-26. https://doi.org/10.1080/00220272.2019.1641843

Heinich, R., Molenda, M., Russell, J. D., & Smaldino, S. E. (2002). *Instructional media and the technologies for learning*. Merill Prentice Hall.

Jeronen, E., Palmberg, I., & Yli-Panula, E. (2017). Teaching methods in biology education and sustainability education including outdoor education for promoting sustainability–A literature review. *Education Sciences, 7*(1), Article 1. https://doi.org/10.3390/educsci7010001

Kim, C., & Fortner, R. W. (2006). Issue-specific barriers to addressing environmental issues in the classroom: An exploratory study. *The Journal of Environmental Education, 37*(3), 15-22. https://doi.org/10.3200/JOEE.37.3.15-22

King, A. P., & Eckersley, R. J. (2019). *Statistics for biomedical engineers and scientists: How to visualize and analyze data*. Elsevier. https://doi.org/10.1016/C2018-0-02241-0

Knippels, M.-C., van Dam, F., & van Harskamp, M. (Eds.). (2017). *Science and society in education*.

PARRISE. https://doi.org/10.21820/23987073.2017.5.52

Kricsfalusy, V., George, C., & Reed, M. G. (2018). Integrating problem- and project-based learning opportunities: Assessing outcomes of a field course in environment and sustainability. *Environmental Education Research, 24*(4), 593-610. https://doi.org/10.1080/13504622.2016.1269874

Kuvac, M., & Koc, I. (2018). The effect of problem-based learning on the environmental attitudes of preservice science teachers. *Educational Studies, 45*(1), 72-94. https://doi.org/10.1080/03055698.2018.1443795

Ladson-Billings, G. (1995). Toward a theory of culturally relevant pedagogy. *American Educational Research Journal, 32*(3), 465-491. https://doi.org/10.3102/00028312032003465

Lateh, H., & Muniandy, P. (2010). Environmental education (EE): Current situational and the challenges among trainee teachers at teachers training institute in Malaysia. *Procedia-Social and Behavioral Sciences, 2*(2), 1896-1900. https://doi.org/10.1016/j.sbspro.2010.03.1005

Levinson, R. (2018). Introducing socio-scientific inquiry-based learning (SSIBL). *School Science Review, 100*(371), 31-35.

Liu, Q., Cheng, Z., & Chen, M. (2019). Effects of environmental education on environmental ethics and literacy based on virtual reality technology. *The Electronic Library, 37*(5), 860-877. https://doi.org/10.1108/EL-12-2018-0250

Makransky, G., & Lilleholt, L. (2018). A structural equation modeling investigation of the emotional value of immersive virtual reality in education. *Educational Technology Research and Development, 66*(5), 1141-1164. https://doi.org/10.1007/s11423-018-9581-2

Marzo, R, Chen, H., Anuar, H., Wahab, M., Ibrahim, M., Ariffin, I. A., Ahmad, A., Kawuki, J., & Aljuaid, M.. (2023). Effect of community participation on sustainable development: An assessment of sustainability domains in Malaysia. *Frontiers in Environmental Science, 11*. https://doi.org/10.3389/fenvs.2023.1268036

Meichtry, Y., & Smith, J. (2007). The impact of a place-based professional development program on teachers' confidence, attitudes, and classroom practices. *The Journal of Environmental Education, 38*(2), 15-32. https://doi.org/10.3200/JOEE.38.1.15-34

Merrill, M. D. (1994). *Instructional design theory*. Educational Technology Publications.

Merrill, M. D. (2002). First principles of instruction. *Educational Technology Research and Development, 50*(3), 43-59. https://doi.org/10.1007/BF02505024

Metcalf, S., Chen, J., Kamarainen, A., Frumin, K., Vickrey, T., Grotzer, T., & Dede, C. (2019). Transitions in student motivation during a MUVE-based ecosystem science curriculum: An evaluation of the novelty effect. In K. Becnel (Ed.), *Emerging technologies in virtual learning environment* (pp. 96-115). IGI Global. https://doi.org/10.4018/978-1-5225-7987-8.ch005

Miyamoto, M., Mohd Parid, M., Noor Aini, Z., & Michinaka, T. (2014). Proximate and underlying causes of forest cover change in Peninsular Malaysia. *Forest Policy and Economics, 44*, 18-25. https://doi.org/10.1016/j.forpol.2014.05.007

Morrison, G. R., Ross, S. M., Kalman, H. K., & Kemp, J. E. (2012). *Designing effective instruction*. Wiley.

Neville, I. A., Petrass, L. A., & Ben, F. (2023). Cross disciplinary teaching: A pedagogical model to support teachers in the development and implementation of outdoor learning opportunities. *Journal of Outdoor and Environmental Education, 26*, 1-21. https://doi.org/10.1007/s42322-022-00109-x

Nunnally, J. C. (1978). An overview of psychological measurement. In B. B. Wolman (Ed.), *Clinical diagnosis of mental disorders*. Springer. https://doi.org/10.1007/978-1-4684-2490-4_4

Paraskeva-Hadjichambi, D., Goldman, D., Hadjichambis, A. C., Parra, G., Lapin, K., Knippels, M.-C., & van Dam, F. (2020). Educating for environmental citizenship in non-formal frameworks for secondary level youth. In A. C. Hadjichambis, P. Reis, D. Paraskeva-Hadjichambi, J. Činčera, J. Boeve-de Pauw, N. Gericke, & M.-C. Knippels (Eds.), *Conceptualizing environmental citizenship for 21st century education. Environmental discourses in science education, vol 4* (pp. 213-235). Springer. https://doi.org/10.1007/978-3-030-20249-1_14

Parra, G., Hansmann, R., Hadjichambis, A. C., Goldman, D., Paraskeva-Hadjichambi, D., Sund, P., Gericke, N., & Conti, D. (2020). Education for environmental citizenship and education for sustainability. In A. C. Hadjichambis, P. Reis, D. Paraskeva-Hadjichambi, J. Činčera, J. Boeve-de Pauw, N. Gericke, & M.-C. Knippels (Eds.), *Conceptualizing environmental citizenship for 21st century education. Environmental discourses in science education, vol 4* (pp. 149-160). Springer. https://doi.org/10.1007/978-3-030-20249-1_10

Robelia, B., & Murphy, T. (2012). What do people know about key environmental issues? A review of environmental knowledge surveys. *Environmental Education Research, 18*(3), 299-321. https://doi.org/10.1080/13504622.2011.618288

Schild, R. (2016). Environmental citizenship: What can political theory contribute to environmental education practice? *The Journal of Environmental*

Education, 47(1), 19-34. https://doi.org/10.1080/00958964.2015.1092417

Shadiev, R., Wang, X., & Huang, Y. M. (2020). Promoting intercultural competence in a learning activity supported by virtual reality technology. *International Review of Research in Open and Distributed Learning, 21*(3), 157-174. https://doi.org/10.19173/irrodl.v21i3.4752

Shadiev, R., Wu, T.-T., Sun, A., & Huang, Y.-M. (2018). Applications of speech-to-text recognition and computer-aided translation for facilitating cross-cultural learning through a learning activity: Issues and their solutions. *Educational Technology Research and Development, 66*, 191-214. https://doi.org/10.1007/s11423-017-9556-8

Smederevac-Lalic, M., Finger, D., Kovách, I., Lenhardt, M., Petrovic, J., Djikanovic, V., Conti, D., Boeve-de Pauw, J. (2020). Knowledge and environmental citizenship. In A. C. Hadjichambis, P. Reis, D. Paraskeva-Hadjichambi, J. Činčera, J. Boeve-de Pauw, N. Gericke, & M.-C. Knippels (Eds.), *Conceptualizing environmental citizenship for 21st century education. Environmental discourses in science education, vol 4* (pp. 69-82). Springer. https://doi.org/10.1007/978-3-030-20249-1_5

Sobel, D. (2004). Place-based education: Connecting classroom and community. *The Kohala Center*. Retrieved September 13, 2024, from https://kohalacenter.org/teachertraining/pdf/pbexcerpt.pdf

Southgate, E. (2018). Immersive virtual reality, children and school education: A literature review for teachers. *DICE Research*. Retrieved September 13, 2024, from https://ericasouthgateonline.wordpress.com/wp-content/uploads/2018/06/southgate_2018_immersive_vr_literature_review_for_teachers.pdf

Stern, P. C. (2000). Toward a coherent theory of environmentally significant behavior. *Journal of Social Issues, 56*, 407-424. https://doi.org/10.1111/0022-4537.00175

Stern, P. C. (2011). Contributions of psychology to limiting climate change. *American Psychologist, 66*(4), 303–314. https://doi.org/10.1037/a0023235

Sukhoverkhov, A., & Dewitt, D. (2024). Evolutionary, cognitive and semiotic foundations of learning in virtual reality. *Filosofiya Nauki i Tehniki, 29*(1), 112-122. https://doi.org/10.21146/2413-9084-2024-29-1-112-122

Sukma, E., Ramadhan, S., & Indriyani, V. (2020). Integration of environmental education in elementary schools. *Journal of Physics: Conference Series, 1481*, Article 012136. https://doi.org/10.1088/1742-6596/1481/1/012136

Tan, W. Y. (2024). *Development of a virtual reality-integrated sustainable environmental education module for Malaysian secondary schools* [Unpublished doctoral thesis]. Universiti Malaya.

Tuck, E., McKenzie, M., & McCoy, K. (2014). Land education: Indigenous, post-colonial, and decolonizing perspectives on place and environmental education research. *Environmental Education Research, 20*(1), 1-23. https://doi.org/10.1080/13504622.2013.877708

UN. (2015). Transforming our world: The 2030 agenda for sustainable development. *United Nations*. Retrieved September 13, 2024, from https://sdgs.un.org/2030agenda

UNDP, UNICEF & EcoKnights. (2020). *Change for climate: Findings from the national youth climate change survey Malaysia*. Retrieved September 13, 2024, from https://www.unicef.org/malaysia/media/1606/file/Change%20for%20Climate.pdf

UNESCO. (2009). Review of context and structures for education for sustainable development. *UNESCO*. Retrieved September 13, 2024, from https://unesdoc.unesco.org/ark:/48223/pf0000187757

UNICEF Malaysia. (2021). Analysis of impacts of climate change and environmental degradation on children in Malaysia and assessment of child-sensitivity of current adaptation and mitigation policies: Technical report. *United Nations Children's Fund*. Retrieved September 13, 2024, from https://www.unicef.org/malaysia/media/2216/file/UNCEF_UKM_Full_technical_report.pdf

Vasconcelos, C. (2012). Teaching environmental education through PBL: Evaluation of a teaching intervention program. *Research in Science Education, 42*(2), 219-232. https://doi.org/10.1007/s11165-010-9192-3

Weil, Z. (2021). *The world becomes what we teach: Educating a generation of solutionaries*. Lantern Publishing & Media.

Yemini, M., Engel, L., & Ben Simon, A. (2023). Place-based education–A systematic review of literature. *Educational Review*, 1-21. https://doi.org/10.1080/00131911.2023.2177260