RESEARCH ARTICLE

Augmented and virtual reality technologies in education for sustainable development: An expert-based technology assessment

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Abstract • Digitalization in the field of education for sustainable development (ESD) has gained attention in the last decade. In particular, technologies such as augmented reality (AR) and virtual reality (VR) offer new ways to deliver educational content on sustainable development by simulating real-world experiences and using immersive and interactive formats for learning. Using an explorative qualitative research approach, the benefits of AR and VR technologies in the context of ESD are assessed. The results of a first expert panel show that AR and VR technologies are particularly suitable for sustainability topics when an understanding of action and the transfer of knowledge and values are to be promoted among learners.

***Augmented und Virtual-Reality-Technologien in der Bildung für nachhaltige Entwicklung**: Eine expertenbasierte Technologiebewertung*

Zusammenfassung • *Die Digitalisierung im Bereich der Bildung für nachhaltige Entwicklung (BNE) hat in den letzten zehn Jahren an Aufmerksamkeit gewonnen. Besonders Technologien wie Augmented Reality (AR) und Virtual Reality (VR) bieten neue Möglichkeiten, Bildungsinhalte zur nachhaltigen Entwicklung zu vermitteln, indem sie reale Erfahrungen simulieren und immersive sowie interaktive Formate für das Lernen nutzen. Mittels eines explorativen qualitativen Forschungsansatzes werden die Vorteile von AR- und VR-Technologien im Kontext von BNE untersucht. Ergebnisse eines kleinen Expertenpanels zeigen, dass AR- und VR-Technologien für nachhaltige Themen dann besonders geeignet sind, wenn ein Handlungsverständnis und der Transfer von Wissen und Werten bei Lernenden gefördert werden soll.*

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Introduction

The transition towards sustainability calls for a far-reaching global change in our societies in order to meet the 17 Sustainable Development Goals of the United Nations, 'which inspires hope for breaking the vicious circle of poverty, inequality and environmental destruction confronting people and the planet' (UNRISD 2016, p. 3). Therefore, a transition towards sustainability addresses both individual agency and collective action by societies. Accordingly, education plays a crucial role in achieving global sustainable development goals and empowering people to address environmental and development issues (Buckler and Creech 2014). This led to the adoption of education for sustainable development (ESD) by the United Nations General Assembly on 20th December 2002.

ESD aims to empower people to think and act responsibly and with respect to the future as well as to develop an understanding of the social, cultural, economic, and environmental impacts associated with their actions on other parts of the planet and generations (Rieckmann 2018; Holfelder 2019). With ESD, learners can acquire competencies to apply knowledge and values about sustainable development, making future-oriented decisions, and participating in sociopolitical processes that move their society toward sustainable development (Buckler and Creech 2014; Rieckmann 2018). Identified key competencies include complex systems thinking, collaborative, forward and critical thinking, self-awareness, and integrated problem solving (Rieckmann 2018; Cebrián et al. 2020)

However, sustainability's complexity, interconnectedness and contradictory nature and components (Purvis et al. 2019) make it challenging to communicate, understand, and train these competencies. Therefore, to achieve a holistic and transformative education that changes capacities into actual, sustainable actions and considers the learning content and results (Heiskanen et al. 2016), more experimental or unconventional training and learning techniques are needed (Molnar and Mulvihill 2003). ESD also requires participatory learning approaches that motivate and empower learners to actively engage in decision-making processes and take action for sustainable development (Fukukawa et al. 2013).

Against this background, digitalization in the field of ESD has gained attention in the last decade as researchers and practitioners alike explore its potentials in creating new learning and teaching techniques to generate and transfer the required skills and competencies (Ahel and Lingenau 2020). While web-training instruments, online learning platforms and assessments to train sustainability-related competencies (Baumgartner and Winter 2014) are becoming more popular, the use of of immersive technologies is still at early stage. Even though immersive technologies are not new technologies in the education sector, the diffusion in the field of ESD is slow. This notwithstanding, they present great potential in sustainability communication and sustainability-related competencies training. Immersive technologies' ability to simulate potential scenarios, immersive visualization of situational data, and interactivity are key components that seem optimal for the application in the topic of ESD.

This paper investigates the potential of augmented reality (AR) and virtual reality (VR) technologies using an explorative expert panel as evaluation in the context of ESD needs both from a macroscopic and microscopic perspective. First, content-related background information and the applied methodology are presented. To this end, domain specific key experts from immersive technologies and sustainability education evaluate the previously identified benefits of AR and VR for the theoretical-generic usability to ESD and specifically on a practical use case. With the presented and discussed results, this paper provides a seminal contribution to effectively and comprehensively strengthen ESD in a society shaped by digitalization.

Analyzing the current application of AR and VR in education and sustainability

AR and VR in education and sustainability

Immersive technologies can be divided into two major technology streams: AR and VR approaches (Milgram and Kishino 1994). AR can be defined as a technology that superimposes a computer-generated image on the real world and in real-time 'thus providing a composite view' (McMillan et al. 2017, p. 163), while VR technology refers to a computer-generated environment that simulates a real situation (Fernandez 2017). AR and VR are able to provide learners with contextual learning experiences by allowing them to explore and discover the real or virtual world with previously inaccessible additional information (Johnson et al. 2016). Extensive and complex data can thus be visualized and conveyed intuitively, helping learners learn challenging and complex tasks (Beckmann et al. 2019). Besides, the features increase engagement and facilitate self- and participant-centric learning (Papanastasiou et al. 2019).

In the education sector researchers and practitioners have been exploring the potential of AR and VR in education and training. For instance, Papanastasiou et al. (ibid.) present the effectiveness of these technologies in terms of training and education in various fields such as health care, operation management and geography. First of all, adapting AR and VR into modern-day education can enhance and motivate learners while providing them with hands-on experiences and offers a new way of reaching out to more people (Bell and Fogler 2004, Shim et al. 2003). These technologies allow learners to actively participate (Beckmann et al. 2019) as well as promote understanding by embedding abstract information directly into the real or virtual world (Jerald 2016). VR creates immersive experiences that resemble the real world while providing virtual flexibility such as making extreme situations accessible in a risk-free (virtual) manner (Jerald 2016). In AR, computer-generated objects allow for perceptually enhancing additions. Extensive and complex information can be visualized and thus conveyed in an intuitive way.

Adapting AR and VR into modern-day education can enhance and motivate learners while providing them with hands-on experiences.

In sustainability research, immersive technologies were discovered in 1990 as part of research on tourism as Dewaily introduced a 3D visualization to reduce the carbon footprint of vulnerable environments (Dewailly 1999). Studies of environmentally friendly behaviors in the term of sustainable economies began with perceiving digital information (e.g., visually, auditory, and haptically). The illusion of 'being there' (so-called 'presence', Witmer and Singer 1998) "was associated with personal decision-making, and interaction with the virtual environment" (Jolink and Niesten 2021, p. 2). The potential applications of virtual reality were designed as so-called 'persuasive technology' to effect attitude change (Wu and Lee 2015). In this regard, there is evidence that serious games and simulations can foster players to inform, educate, and train on sustainability.

The 2005 proposal by Summerville et al. is among the first to underline immersive technologies in encouraging people to engange in environmentally sustainable behavior. An in-depth overview by Scurati et al. 2021 contains a comprehensive survey of potentials and recommendations for an optimal implementation. Other contributions that show interfaces with the use of immersive technologies and sustainable development include VR as a persuasive technology to promote sustainability (Song and Fiore 2017) or AR for citizien-centered design in urban planning (Saßmannshausen et al. 2021).

AR and VR specific pedagogical remarks

The active use of human senses and motor skills enhances learning and understanding (Dale 1969). Edgar Dale postulated back in 1969, according to the 'Cone of Experience', that the level of involvement is critical to learning effectiveness. He distinguishes between passive and active involvement: Active involvement, such as simulating real experiences or doing real things, contributes to the strongest memorability. Both passive (verbal and visual reception of information) and active involvement is connotated strongly with the degree of presence in AR and VR (Witmer and Singer 1998) and is achieved through the interactive character of AR and VR.

In the past years, a paradigm shift took place in the prevailing learning theories from teacher-centered learning models to learner-directed approaches (constructivist approaches). Constructivist approaches are mainly used to highlight and contrast important aspects of immersive learning environments (Hütter and Lang 2017). Through constructivist learning methods, individual experiences and subjective relevance to action are to be obtained by placing the learner in a practical-subjective situation (Loyens and Gijbels 2008). Typical examples include simulations or business games in which participants experience scenarios to which they independently explore solutions for complex tasks and challenges as a reaction. In this way, they construct new knowledge situationally and directly experience the success of the applicability of this self-generated competence (Loyens and Gijbels 2008).

Criteria for assessing AR and VR in the context of ESD

In oder to derive criteria for assessing the potentials of AR and VR in the education for sustainable development an in-depth literature review was conducted, which is under publication in a separate paper. The following list presents the summary of the results of (five) clustered ESD needs and (seven) benefits of AR and VR in education. Each cluster is defined, which is necessary for a common understanding in the expert evaluation, as summarized in the following.

Educational needs for sustainable development:

- Knowledge and values: Gaining orientation knowledge on sustainable development, i.e., developing an understanding of complex structures, as well as learning to understand social and ecological aspects from a global perspective and how to deal with social norms and values.
- Sense of responsibilty: Development of intrinsic motivation and responsible behavior as well as sensitivity to the environment.
- Decision-making: Fostering thinking patterns to contribute to a more reflective decision-making of the individual, including critical thinking, future-oriented thinking but also creativity.
- Understanding of action: Creation of spaces for experimentation and design in order to model sustainable behavior as well as to be able to act autonomously, taking problems or resistance into account.
- Participation: Interdisciplinary design by involving various stakeholders and ensuring participation in decision-making processes.

AR/VR benefits:

- Interactivity: Real-time interaction as well as social interactions, a feedback mechanism is possible by giving comprehensible reactions.
- Simulation: Creation of innovative and experimental scenarios and a variety of explorative options.
- Immersion: Creation of virtual environments such as virtual laboratories, 3D visualizations enabling a realistic perception.
- Collaboration: Learning in virtual communities, which can also create group cohesiveness.
- Learnability: Increasing cognitive learning, i.e., concentration skills, contexts and relationships to be able to learn independently of location and time.
- Engagement: Increasing motivation through fun and playful learning.
- Cost Effectiveness: Lowering the risk of sunk costs due various scenarios being displayed through off-the-shelf devices.

Methodological approach to assess the potential of immersive technologies in the field of ESD

To address the previously introduced potentials of VR/AR in the field of ESD, we apply an explorative qualitative research approach in a form of an expert panel discussion. This method has been chosen, as we want to understand concepts, opinions and experiences of experts to develop a deeper understanding of potentials of VR/AR applications in ESD from different perspectives.

As basis for the panel, the identified ESD needs and relevant benefits of AR/VR technologies served as a guideline. Prior to the panel discussion, the experts were provided with the criteria asked for the completeness or redundancy of the categories to be evaluated. The whole expert panel took place in May 2021 via a videoconference due to the ongoing Covid19 pandemic and was recorded for later transcription and analysis. The evaluation process was implemented by a Miroboard (virtual whiteboard for online collaboration). The resulting analysis was sent to the involved experts in order to receive corrections and additional comments on the findings. The discussion is conducted in two rounds: In the first round of expert discussion, the techni-

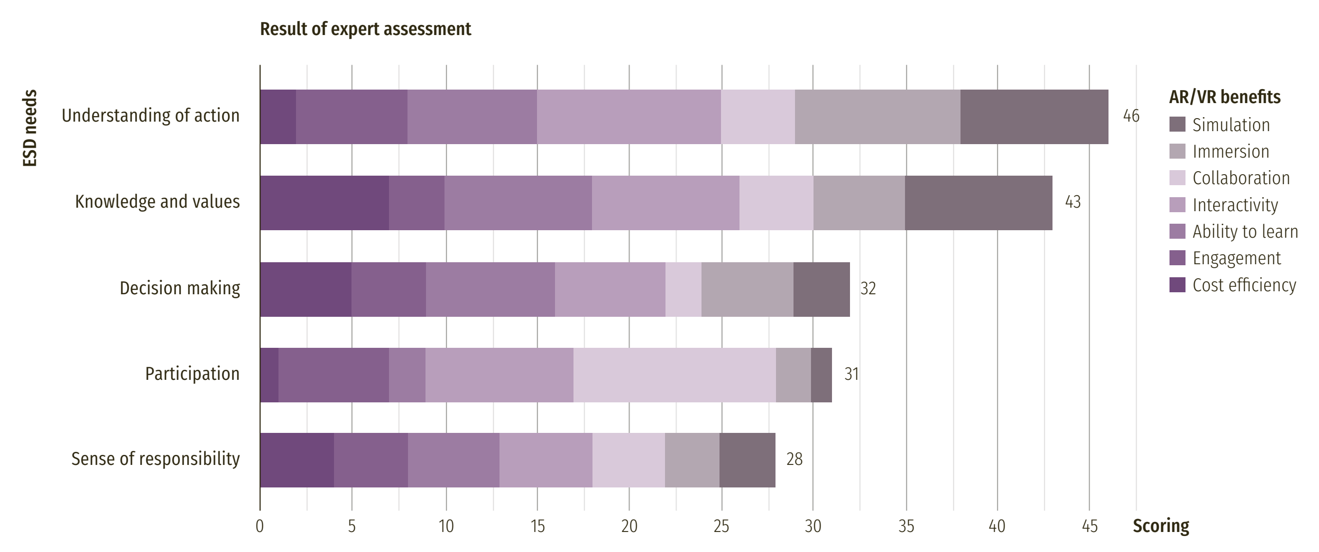

Figure 1: Visualization of the distribution of the points of the pairwise weights of AR/VR benefits to ESD needs. *Source: author's own compilation*

cal benefits of AR and VR are allocated with the needs of ESD. The first test is used to evaluate the usability of AR and VR in a generic perspective. For this purpose, the method of pairwise comparison has been applied, according to which the identified categories of AR/VR and of ESD were to be weighted followed by a discussion of the results afterwards.

In the second round, we contextualise this input to a specific use case and a more applied perspective. Therefore, a concrete case of an urban greening application (UGa) was introduced. The application aims to enable citiziens to view, understand and evaluate urban redesigns on site in a three-dimensional, immersive way, independent of time. This in-house prototype enable citizens to enrich three-dimensional city models with greening modules in AR and inform themselves about environmental impacts and maintenance needs. Thus, a knowledge transfer in addition to participation in the planning process is intended. Due to previous discussions in a research project, all experts are informed about the development of the application (current prototype status). The second round aims to classify the urban greening approach to the requirements of ESD.

The panel includes five stakeholders representing different disciplines, by a random selection process from a list of potential experts: Two AR/VR technical experts, an architect and an urban planner as experienced practitioners and a specialist in innovative education concepts in the context of sustainable development and transformation.

The five experts are composed on the basis of the following expertise:

- Expert 1: Founder and owner of office for planning and construction processes in the field of urban planning, landscape architecture and civil engineering for 30 years, using different digital solutions.
- Expert 2: Educational expert and speaker in the field of innovative learning, teaching and research concepts for 10 years and leader of different projects in the areaof ESD.
- Expert 3: Developer of computer games in the entertainment industry for 16 years and self-employed with AR/VR studio for four years.
- Expert 4: Owner of architectural office for 17 years and winner of various local and international competitions.
- Expert 5: Computer science professor in the field of human-computer interactions for 10 years.

Results and discussion of the expert assessment

Test 1: Benefits of immersive technologies in ESD

Regarding how AR and VR can meet the needs of ESD, the weighting of the pairwise comparison and the distribution of the experts' scores is shown in Figure 1. The bar chart is color-coded according to the identified benefits of AR and VR technologies. The experts' evaluation indicates that the technical possibilities of AR and VR are mostly linked to an improved understanding of action with a total of 46 points and the improved communication of knowledge and values of sustainable development with a total of 43 points. Overall, interaction and simulation, and immersion, in particular, are considered to have a decisive advantage.

The qualitative analysis of the discussion contextualizes these quantitative results as follows:

The experts agreed that through the technology specific benefits interactivity, simulation, and immersion of AR/VR, the understanding of action is most pronounced since the learning process is triggered by oneself as an self-initated action. In addition,

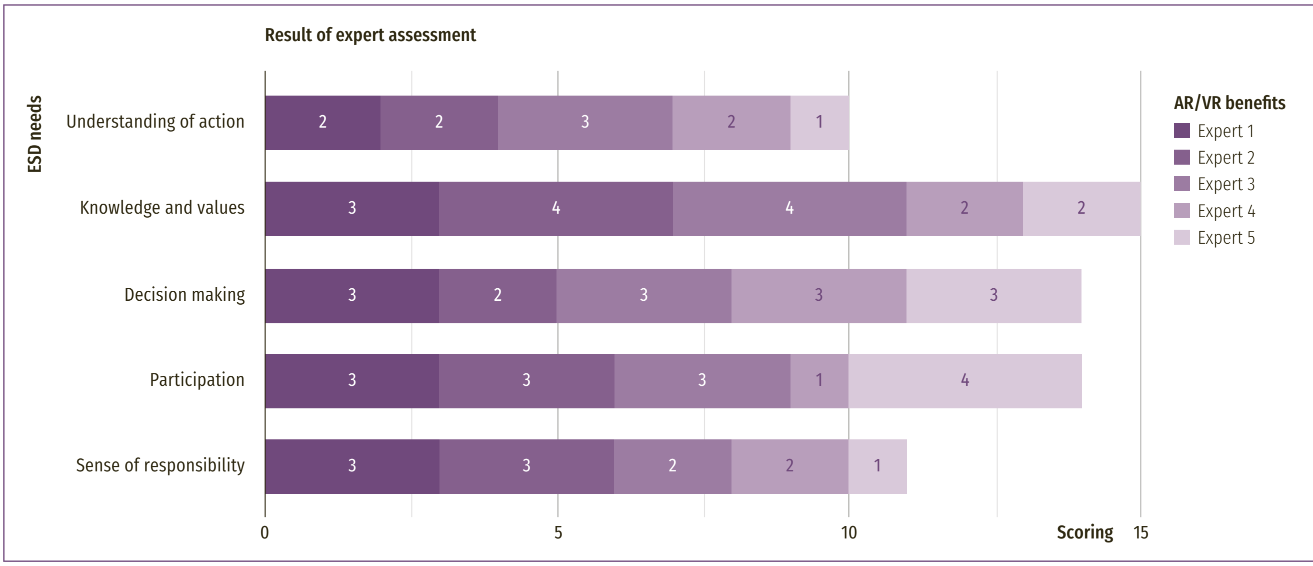

Figure 2: Benefits of use case urban greening to ESD needs. *Source: author's own compilation*

through the immersion, the actions are deepened by the emotional involvement of the learner.

The sustainability education expert saw, above all, strong connections between participation and engagement on the bases that a positive connotation prevails in participatory processes. In turn, the motivation is increased to get involved on a lasting basis (engagement).

The pairwise comparison of decision-making and learning ability was given a high score according to the experts, as the ability to show contexts and relationships and location-independent learning leads the learner to make reflective decisions.

Finally, the experts discussed that the combination of cost-effectiveness to ESD requirements was difficult to evaluate because no concrete link or example use case could be established.

Test 2: Context based potential of immersive technologies in a specific application

In a second discussion round, the experts were presented with an approach to visualizing urban greening and its sustainability effects. The UGa uses AR and VR to visualize (planning) models and urban redevelopments in real spaces without costly and time-consuming physical prototypes. Based on this use case, the experts were asked to evaluate the potentials of AR/VR in relation to ESD in this specific approach.

Figure 2 shows the results of this evaluation on the benefits of the UGa adressing ESD needs. Similar to the previous figure, the distribution of points is color-coded, but this time with regard to the experts' point distribution.

In summary, the UGa was rated most appropriate for the goals of knowledge and values, decision making, and participation of ESD. The high rated potential for participationis a proof for the approach of the UGa, since it primarily aims to be a citizen participation tool designed for low-threshold accessible feedback in decision-making processes and virtual co-creation by the individual.

The qualitative analysis of the discussion contextualizes these quantitative results as follows:

Specifically, in this use case, the experts assigned a lower contribution to action understanding than the evaluation in total in Figure 1 because users cannot judge whether greening works the way they apply it. To generate a deeper understanding of action, appropriate time and mediation is a prerequisite.

One of the AR/VR expert noted that not all ESD requirements can be addressed simultaneously, but rather build on each other in different phases. From the input knowledge grows the other requirements such as understanding of action and sense of responsibility, because without prior knowledge, the far-reaching consequences of one's own actions are not visible. The experts point out that due to the aforementioned characteristics, the use of the UGa should not be a one-time experience in order to achieve an optimal benefit in terms of ESD.

Finally, there was a consensus under all experts that potentially all needs of ESD can be achieved by using AR and VR applications. is decisive for best outcome.

Conclusion

As emerging and versatile technologies, AR and VR have the potential to transform ESD. To gain a deeper understanding and foster further development in this direction, we first identified five characteristic ESD needs and seven AR/VR benefits from existing literature. These aspects were used as guideline for an expert discussion with five stakeholders covering a technical, theoretical and pratical backround. The results of this expert-driven technology assessment show that AR and VR technologies are effective instruments to promote ESD, primarily due to their simulative and interactive properties making a decisive contribution to the transfer of knowledge and values as well as to the understanding of action. The characteristic of cost-effectiveness was revealed to be difficult to compare within ESD requirements. In the context of the UGa, the positive aspect of knowledge transfer was also identified, and, in addition, a particularly profitable effect on decision-making and participation became visible. Addressing all ESD requirements in parallel seems not feasible because some of the requirements build on each other. The expert discussion also showed that the degree of fulfillment of ESD needs depends on the very objective and implementation of the AR/VR application. In the specific use case of the presented UGa, no holistic understanding of action is assumed, but the criterion of participation is fully met. In summary, the technologies include the ability to improve all of the five identified prerequisites for educating sustainable development. Overall, the main potential is seen in understanding action and knowledge transfer, but individual AR/VR applications can also have a positive impact of decision-making and participation.

As limitation of our outcome the yet small number of experts and only one (prototype) use case must be mentioned. Given that immersive technologies are insufficiently explored in the context of ESD, our paper is a initial step towards broader dissemination. However, this paper provides an entry point of digital approaches supporting the effectiveness of learning outcomes in terms of ESD and how AR and VR potentials can be applied towards more sustainable development. The tremendous capabilities of these technologies may enable breaking the boundaries of traditional education.

Further research should evaluate the effectiveness of immersive and interactive AR and VR in various use cases in educational contexts and examine outcomes such as attitude, collaboration, action understanding and decision-making skills, changes in sustainable development education and behavior, and adverse effects. In particular, valid methods need to be found that can make more profound statements about actual behavioral changes and decision-making, and which also test and evaluate theory-based approaches.

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