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Ethical issues of educational virtual reality

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A R T I C L E I N F O

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A B S T R A C T

In response to the high demand for digital learning as a surrogate for physical experiences, virtual reality (VR) is positioning itself as a tool for creating educational virtual experiences. VR technology faces a number of ethical issues, including a reduction of users' autonomy, health problems, and privacy concerns. The use of VR and realism in education can turn out to be a double-edged sword. While realistic visualizations can promote learning for some content domains, they can hinder comprehension in others. Furthermore, the effects of realism on learning also depend on learners' spatial abilities. Letting young children and teenagers engage in virtual educational experiences can expose them to manipulation, could lead to health issues, and may infringe on their privacy. In short, realism and virtual experiences may severely limit learners' autonomy in a number of ways. Based on a review of the literature and considerations of emerging technologies such as generative artificial intelligence, this paper presents guidelines for the ethically sound utilization of VR and realism. By applying findings and conclusions established in the context of research on the ethics of VR to the educational utilization of this technology, I develop several suggestions that may help to avoid negative consequences of educational VR. These suggestions include the utilization of spatial ability testing, requiring virtual experiences to offer alternative paths to prevent manipulation, as well as using algorithms that deidentify the highly detailed developmental profiles that can be generated through educational VR use.

1. Introduction

Recent years saw a tremendous global effort in the digitalization of education, stemming in part from the interesting and novel opportunities offered by technology as well as the important role that digital education played during the COVID-19 pandemic. As a result of travel restrictions, social distancing regulations, and school closures, digital technology has established itself as a substitute for in-person education. In order to recreate entire experiences beyond the means of traditional digital media such as websites and videos, there is an increased demand for virtual environments, either realized using virtual reality (VR) head-mounted displays, as desktop VR using regular screens, or utilizing combinations of real and virtual components using augmented reality (AR) or mixed reality (MR). However, VR and realistic virtual worlds have been analyzed regarding their potential drawbacks for years. In this paper, current ethical issues on the psychological and cognitive effects of VR as they pertain to education are presented and analyzed. The aim of this paper is to find solutions for an ethical use of this technology. By closely analyzing the potentials and problems of learning utilizing VR and related technologies from a cognitive, educational, social, and privacy perspective, the guidelines for the ethical use of educational VR are established.

In the following sections, definitions of realism underlying VR use and components of virtual experiences are introduced. Subsequently, I summarize the main ethical issues of VR resulting from the possibilities allowed by this technology. Broadly spoken, these issues include privacy, autonomy, and equal access. The main research question behind this paper is whether there can be solutions to ethical problems posed by educational VR at the individual and societal level. The paper is structured to offer definitions and a review of the literature, followed by a summary of the ethical issues raised in the literature and through a critical consideration of current research results. Finally, solutions to these issues are proposed and translated into principles for the ethical use of educational VR.

1.1. Literature review

1.1.1. Realism and virtual reality

At the core of VR lies visual realism, allowing us to perceive a virtual world that looks and behaves comparable to our physical environment.

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Visual realism is generally understood as the degree to which a representation matches a real object or scene (e.g., Rieber, 1994). Using traditional visual media, representations can be produced in a wide variety of realism levels, such as detailed and shaded pencil drawings, schematic line sketches, or elaborate paintings. VR and computer-generated imagery have introduced even more ways to create visualizations varying in their levels of realism (Skulmowski et al., 2022). In a virtual world, objects are created as geometrical constructs, often starting with a primitive shape (such as boxes or cylinders) that can be further refined, shaped, and detailed until they resemble a real object closely enough (Skulmowski et al., 2022). Slater et al. (2009) call this dimension *geometric realism*. These three-dimensional objects can then be rendered using more or less physically correct lights to generate an image output. The realism achievable by using realistic lighting was named *illumination realism* by Slater et al. (2009). Building on Slater et al.'s (2009) model and more recent developments in the field of computer graphics, Skulmowski et al. (2022) proposed the *geometry*, *shading*, *rendering* model. With the geometry and rendering dimensions largely similar to the geometry and illumination categories of Slater et al. (2009), the additional shading dimension emphasizes that the application of image files to the objects can greatly affect realism. Image files can be applied as a color layer with the possibility to "draw" more detail onto the model without requiring additional geometry (Skulmowski et al., 2022). Furthermore, image files can be used to give objects additional realistic surface properties, including adding shine to specific areas and the simulation of fine details such as scratches (Skulmowski et al., 2022).

Beyond visual realism, a convincing virtual environment requires additional forms of realism. A crucial component to realism in VR is *behavioral realism*, which can be achieved by having virtual agents behave as real humans (Bailenson et al., 2006; Kyrlitsias & Michael-Grigoriou, 2018). In addition to what is being presented to users, the mode of interaction can also feel more or less realistic (or natural). This can be achieved with *natural user interfaces* that involve gesture controls (e.g., Falcao et al., 2015), removing the need for less natural keyboard and mouse controls.

In summary, realism in VR consists of several facets, including visual realism, behavioral realism, and the mode of interaction. Out of these possibilities to construct a new reality that may become indistinguishable from the physical reality (Slater et al., 2020), several ethical problems arise that will be summarized in the following sections.

1.1.2. The ethics of virtual reality

After having defined realism, it is necessary to turn towards the ethical challenges that result from the possibility to replace humans' perceptual input streams with computer-generated signals. In an influential paper, O'Brolcháin et al. (2016) discuss several ethical issues of VR with a focus of social interactions and virtual social networks. They describe how the (potentially) addictive nature of digital technologies combined with the surveillance made possible by them can pose a threat to users' autonomy. Moreover, they highlight that VR may be misused to propagate a distorted view of the world and to manipulate users. O'Brolcháin et al. (2016) even acknowledge the possibility to "brainwash" people if technologies such as brain-computer interfaces are utilized together with VR, having the potential to further reduce users' autonomy. Additional risks identified by them are peer-pressure and conformity, the quantification of an enormous amount of user variables, and the problem of escapism.

Another important contribution to VR ethics was presented by Spiegel (2018). Spiegel raised four major issues concerning VR: (1) adverse mental health effects (e.g., derealization disorder), (2) bodily neglect, (3) privacy concerns stemming from the amount of data collected and methods of manipulating attitudes and behavior, and (4) the blurring between the real and virtual world. Spiegel emphasizes the health risks associated with VR, for instance a collection of symptoms including nausea and fatigue referred to as *cybersickness* (LaViola, 2000). As solutions, Spiegel (2018) proposes a content rating system, content warnings, age regulations, transparent privacy policies, and data protection laws.

Building upon these key issues, Slater et al. (2020) compiled a comprehensive list of potential adverse effects of VR use with an emphasis on the realism aspect of the technology. They call the high level of realism likely to be achievable soon *superrealism*. They list a variety of factors that may develop into problematic issues. One of these issues is that children and vulnerable groups that may not be able to fully distinguish the physical from the VR could gain (unrestricted) access to the technology. In a similar vein, healthy adults may also be at risk from suffering from body dysmorphia if they perceive their virtual body as more attractive than their physical body. In addition, they consider VR to have the potential to contribute towards negative stereotypes through virtual interactions. Beyond this major theme of the blurred lines between reality and cyberspace, they summarize a number of privacy issues that need to be taken into account. As a result of the richness of data that can be easily collected using VR technology as previously highlighted by Spiegel (2018), including motoric and behavioral profiles, identity theft poses a serious threat for virtual societies according to Slater et al. (2020): Artificial, but convincing memories resulting from staged virtual interactions may be hard to shake off (Slater et al., 2020). Additionally, they highlight the persuasive qualities of VR that can easily be exploited for a personalized "bombardment" with virtual advertising. As a solution of this central problem of an artificial reality that is too believable to be easily ignored and too persuasive as to be dismissed, Slater et al. (2020) offer a number of suggestions. They propose content warnings, an adjustable level of realism (to have the choice of seeing a scene in a less persuasive style), educating content creators and users, and data protection measures. In short, this proposal could be summarized as restoring users' autonomy and shielding them from the mentally penetrating characteristics of the virtual experience.

In summary, previous analyses of the ethical challenges brought about by the use of VR have identified threats to personal autonomy through manipulation, privacy issues, and negative effects on health as major issues. Suggested solutions include content warnings, methods of reducing the level of realism to prevent being manipulated, and data protection laws. In the following sections, the specific problems that may arise from the use of VR in education are discussed.

2. Ethical issues of educational virtual reality

Based on the preceding overview of VR ethics, I analyze current and future issues in the utilization of VR in educational settings. These issues cover the role of realism in learning, the ethics of virtual educational experiences, and data protection aspects of learning in VR. These issues were arrived at by applying the ethical issues of VR to the field of educational VR, incorporating several results from the educational sciences.

2.1. VR is not equally beneficial for all types of learning

One of the important aspects to consider in deciding if the utilization of educational VR is ethically advisable is whether educational VR actually enhances learning compared to other methods. Research has shown that educational VR can indeed boost learning performance for certain outcomes, while having little effect on others. In the *cognitive affective model of immersive learning* (CAMIL) presented by Makransky and Petersen (2021), the unique affordances enabled by educational VR, namely presence and agency, are summarized to have an impact on numerous factors involved in learning, such as interest, motivation, and cognitive load (see also Dalgarno & Lee, 2010, as cited by Makransky & Petersen, 2021). Importantly, Makransky and Petersen argue that these possibilities offered by VR do not necessarily enhance the learning performance regarding facts and concepts, but rather present an opportunity to generate experiences that allow procedural and transfer-oriented learning to occur. This distinction is highly important, as it highlights that educational VR is not a panacea. Numerous studies have revealed that VR can indeed lower learning performance (e.g., Makransky et al., 2019), possibly by inducing unnecessary cognitive processing and distracting learners (Mayer et al., 2022). Knowledge concerning the utilization of immersive environments has been named *immersive literacy* by Steed et al. (2023) and is defined by them to include knowledge regarding the egocentric perspective of the VR medium, presence, and other effects. In addition, they argue that this concept will need further development.

This complex set of results underlines that educational VR is likely to be effective only under certain circumstances. An immediate ethical consequence of this conclusion is that educators wishing to utilize VR must be (made) aware of these divergent effects. Even a well-intentioned but uninformed utilization of educational VR could be considered as ethically questionable, given that there may be more effective methods of instruction for specific learning tasks.

2.2. Realism and learning

The realistic nature of VR, either presented using head-mounted displays or as "desktop VR" on regular PCs and screens, has a number of benefits and disadvantages that need to be carefully balanced against each other (Skulmowski et al., 2022). One of the most important uses of realism is the presentation of detailed computer-generated imagery for educational purposes. The potential advantages of realism for learning have been investigated for decades, notably by Dwyer (1967, 1969). Dwyer's studies highlight that there is no linear correlation between the level of realism and learning scores. Instead, realistic details may be considered helpful for specific aims. A recent review comes to a similar conclusion, summarizing that learning tasks focused on visual knowledge of objects often benefit from realism, while the acquisition and application of abstract knowledge usually can be accomplished more effectively using abstract visualizations (Skulmowski et al., 2022).

There are several aspects to consider when using realism in education that introduce their own sets of ethical problems. For instance, realism can heavily skew learners' and educators' perception of the learning process. Realistic visualizations have been found to appear more demanding for learners (e.g., Skulmowski, 2022), potentially affecting how they engage with the learning task. Conversely, laypeople may have a too enthusiastic attitude towards realism that is not backed up sufficiently by empirical evidence (Smallman & St. John, 2005), which may at least in part also be the case for educators and learners. The notion of *naïve realism* (not to be confused with the homonymous epistemological theory) summarizes that laypeople often have a tendency to assume highly positive effects of realism on task performance, primarily based on the misunderstanding that perception works just like a camera, faithfully recording even the smallest visual detail (Smallman & St. John, 2005). Previous research suggests that (pre-service) teachers are particularly prone to misconceptions regarding the cognitive system (Hughes et al., 2020; Tardif et al., 2015) as well as concerning the use of multimedia in learning (Prinz et al., 2022). For example, pre-service teachers have been found to falsely believe that presenting information in learners' preferred "learning style" (such as visually or auditory) boosts learning or that people use only 10% of their brain (e.g., Dekker et al., 2012; Dündar & Gündüz, 2016). Similarly, myths regarding the advantages of certain media exist, such as that videos are a superior instructional format due to their ability to act on multiple sensory modalities (Prinz et al., 2022). Therefore, it is very likely that a substantial part of (pre-service) teachers also at least implicitly approve the misconceptions thought to result in a naïve perspective on realism (such as the perceptual system working like a camera, see Smallman & St. John, 2005), likely leading to an overconfidence in the utilization of realistic visualizations. However, research needs to be conducted to verify whether (pre-service) teachers actually exhibit this overconfidence as described by Smallman and St. John (2005).

An overconfidence of educators in realism would be particularly dangerous due to the divergent effects that realism can have on different groups of learners. A conspicuous and robust result found in the field of instructional psychology is the finding that realism is helpful for learners with high spatial abilities, while learners with low spatial abilities may have a harder time learning with realistic visualizations compared to more simplified versions (e.g., Berney et al., 2015; Huk, 2006; but see also Lee & Wong, 2014). As Reilly et al. (2017) summarize, spatial ability is the largest gender difference found among the cognitive abilities and may be one of the causes behind the gender gap in science, technology, engineering, and mathematics (STEM) fields. Therefore, students' spatial abilities should be more strongly considered by educators when realistic visualizations are to be used. This could be accomplished by conducting tests for spatial ability that are readily available for different age groups (e.g., Quaiser-Pohl, 2003). Importantly, spatial abilities can be trained (e.g., Tzuriel & Egozi, 2010). Thus, the potential problem of a threat to equal opportunities as a result of realism usage can be mitigated. Educators should be made aware of this issue and may want to use spatial ability tests in order to screen for students at risk. Furthermore, teachers should utilize ways to train spatial abilities to further reduce the potential for detrimental effects of realism.

In sum, realism has been found to improve the learning performance in a number of studies, thus suggesting that it would only be ethical to provide learners at least with an option to learn using realistic materials. However, overconfidence in realism needs to be countered as well as misconceptions regarding cognition and media. Furthermore, learners and educators need to be made aware that realism may also have negative effects on learning in some content domains, primarily those concerned with abstract knowledge. Importantly, realism can affect learners in a divergent manner based on their spatial abilities. Thus, it is necessary to screen for low spatial abilities and to offer less detailed alternatives if needed.

2.3. Realism as a facilitator for experiences

In addition to the most critical aim of educators—increasing learners' knowledge—education typically also has other objectives, such as providing learners with significant experiences. In the physical world, this can be achieved through field trips, excursions, and tours. In response to the limited possibilities of movement and travel imposed in many countries in response to the COVID-19 outbreak, the demand for virtual surrogates of these activities rose dramatically (Mercer et al., 2022). A large body of research has resulted in promising results concerning the effectiveness of virtual field trips and similar simulated activities (e.g., Cheng, 2022; Han, 2021; Klippel et al., 2020; Petersen et al., 2020; Shadiev et al., 2022; Zhao et al., 2020; Zhao et al., 2022). One of the most important characteristics of these virtual activities consists in their potential to generate *experiences* (Markowitz & Bailenson, 2021). However, it is rarely acknowledged that the design of such experiences is not only educationally significant, but also ethically relevant, primarily because of the strong effects of VR on cognition and persuasion. VR may prevent users from keeping a psychological distance from the content that is being experienced (Slater et al., 2020). Beyond the undoubtedly high importance of showing that virtual field trips can have a substantial impact on attitudes, we need to carefully consider how an application of this method could affect students and school life.

A significant risk of a wide-spread and frequent use of virtual experiences could be described as the dangers of forcing experiences lacking autonomy and agency on students. For instance, a simulator aimed at providing the experience of suffering from a disease is likely to show the worst potential outcomes rather than demonstrating that mild symptoms are also a possibility. By severely limiting users' agency through sending them on a predetermined path of disaster, such experiences not only lack nuance, but also breach the ethical principle of autonomy (see O'Brolcháin et al., 2016). Thus, a well-intentioned cautionary experience presented using VR technology may turn out to be an exaggeration of reality, potentially distorting learners knowledge and judgment concerning the presented issues. Furthermore, virtual educational experiences, if carelessly designed, may bear a striking resemblance with the potential "bombardment" with advertising and persuasive messages of which Slater et al. (2020) warned in their paper. Realism can have a strong persuasive component (Skulmowski & Rey, 2021), potentially diminishing learners' autonomy over their attitudes. However, the precise consequences of a habitual stream of virtual "conditioning" through experiences with such predetermined (negative) outcomes still need to be determined. It is plausible that educational VR experiences lacking in autonomy with a detectable intention of attitude change could face the problem of being identified as an attempt at manipulating learners' attitudes and beliefs. However, research is needed to confirm this hypothesis.

Ethically even more dubious would be a situation in which the aforementioned blurring between the virtual and real world highlighted by Slater et al. (2020) is exploited to plant memories with a manipulative intent, perhaps with the aim of influencing attitudes or creating a worldview disconnected from facts. While other media and instructional approaches are also capable of generating lasting impressions (both in a positive and a negative way), the highly immediate method of presentation enabled by VR may have such a strong emotional effect (see Makransky & Petersen, 2021) that manipulation is substantially easier to achieve. As evidenced by the effects of VR (horror) games, the arousal that can be induced with this technology is hard to achieve using traditional media (for studies on arousal and fear in VR, see Lemmens et al., 2022; Tian et al., 2021). Thus, research is needed to determine whether and how it is possible to let learners keep their cognitive distance from the contents displayed in VR in order to be able to critically reflect upon them.

2.4. Social aspects of educational VR and privacy

Several issues of social VR discussed by O'Brolcháin et al. (2016) and Slater et al. (2020) have an even deeper impact in educational settings, in particular with children and teenagers involved. As outlined by these authors, VR technology can be used to continuously collect an enormous amount of data; for an example of how these possibilities can be employed for research, see Dubovi (2022).

It is known that merely keeping track of distances between virtual agents and avatars can provide insights into attitudes (Dotsch & Wigboldus, 2008), while a number of physiological data sources can result in an even more precise *digital fingerprint* (Halbig & Latoschik, 2021). This data may be used in yet unforeseeable ways. The field of psychiatry is currently embracing the tools given by the incidental data collection of smartphones via a variety of sensors and data logging methods as a tool for diagnosing psychiatric diseases. This approach is known as *digital phenotyping* (Insel, 2017; Onnela, 2021). As VR offers even more detailed data of users' behavior than smartphones, a number of potential uses are possible. It is feasible to detect and store data regarding attention patterns using built-in eye trackers, attitudes and emotional reactions to specific tasks, social behavior, competencies, and abilities.

One particularly sensitive aspect relevant to data protection concerns the utilization of eye trackers that are increasingly often built into VR head-mounted displays (for an overview of eye tracking in VR, see Adhanom et al., 2023; for reviews of eye tracking in VR, see Rappa et al., 2022; Shadiev & Li, 2022). Eye tracking provides insights into how attentive learners are (Goldberg et al., 2021), their motivational states (Sharma et al., 2020), and can even be used to assess people's expertise using pupil diameter differences (Castner et al., 2020). In VR, eye tracking may be utilized to detect fatigue (Souchet et al., 2022) and can also deliver data regarding users' attitudes, for instance by allowing an estimation of perceived user experience from gaze data (Gao & Kasneci, 2022). Furthermore, eye tracking can be used to infer users' gender (Gao et al., 2022). As behavioral data gathered using head-mounted displays and their sensors has been found to be sufficient to identify VR users, thus acting as biometric data (Pfeuffer et al., 2019), the richness of these datasets can pose serious problems for learners' privacy and data sovereignty.

Regular use of VR throughout people's education could result in developmental measurements of these variables. It can only be speculated what an unregulated ecosystem using these data could mean for the lives of learners involved in a massive data collection scenario. One hypothetical scenario to illustrate these dangers would be a merger of education and employment-related data usage. If a company providing educational VR content could get access to the data collected throughout students' education without restrictions, it would possess an eerily detailed profile of students' personalities, abilities, and (mental) health that would be of high interest for a range of business models, job websites in particular. Without an appropriate informed consent model regarding such data, in an extreme hypothetical example, graduates could end up being surprised over their data having been assembled into an entire digital model of themselves. Such a model could allow predictions concerning job suitability, among other purposes (for overviews of AI-based recruitment, see Köchling & Wehner, 2020; Vrontis et al., 2022). As a result, children and their parents need to be informed and should be asked for their consent for educational VR use. Privacy regulations need to be strictly limited to well-defined uses of the collected data that restrict their transfer.

3. Future ethical issues of educational VR

Beyond the current issues just discussed, there are several new developments surrounding VR in education that are likely to have a bearing on educational VR use in the future. The following sections explore aspects of educational VR that could become problems in the future, in particular in combination with emerging technologies. The ramifications of these aspects can only be speculated upon at this time, but should be closely investigated empirically in the near future.

3.1. Changes in historical interpretation

Over the course of time, historical figures once revered can become less respected or even despised as revelations concerning them come to light (or as societal norms change). Similarly, the historical interpretation of events and groups may develop as well. As discussed above, realism can have a highly persuasive influence on users. Therefore, it is yet unknown whether it would be feasible to rectify a memory gained from a highly realistic virtual experience, especially after a long time has passed since this impression was imprinted. Due to the convincing nature of realistic presentations, research is needed to determine whether virtually-created inaccurate memories can be corrected at a later point in time.

3.2. AI for real-time interaction and content creation

Recent years have brought us tremendous advances in the application of artificial intelligence (AI), in particular in the context of education (Hwang et al., 2020). For example, AI image generators are able to create graphics in a number of styles from short text commands (Frolov et al., 2021). While many AI-generated visuals have a pleasant look to them, some results possess a rather jarring or uncanny appearance, featuring (slightly) deformed objects and body parts (see McCormack et al., 2023). Due to the persisting occurrence of incorrect visual data, at least for some content domains (e.g., Adams et al., 2023), the unsupervised usage of AI-generated visuals for education currently is not to be recommended.

The first generative AI applications for the creation of three-dimensional models and entire virtual worlds are currently appearing, with the potential to drastically reduce the required time and cost of content creation. However, this combination of AI and VR could lead towards a trend of content creation without (sufficient) human oversight, potentially confronting users with incorrect, unsettling, and even haunting worlds and virtual agents. Appropriate methods and standards for safeguarding educational VR from creating misleading, disturbing, and traumatic experiences will need to be devised. One solution for this problem may be to include additional rounds of (AI-based) checks for automatically generated content. For instance, images and models of emotionally sensitive content could be cross-checked by a humans or possibly a different AI model trained to detect potentially disturbing content. This method could prevent having learners interact with virtual agents and environments that have an unsettling look to them. In any event, the use of AI-generated content in educational VR will require the inspection of models by refined automated methods or human oversight. The real-time generation of content should only be considered when well-proven automated safeguarding methods have been established.

3.3. VR and brain-computer interfaces

The combination of VR and brain-computer interfaces (BCIs) may turn out to be a highly manipulative tool as already stated by O'Brolcháin et al. (2016). It has been argued that the use of BCIs by itself lowers personal autonomy, as BCIs can be considered as an influence on users' choices and behavior (Friedrich et al., 2021). Furthermore, it has been emphasized that the large-scale data collection (and the trading of these data) that can be accomplished through BCIs could turn out to be particularly disadvantageous for vulnerable people, requiring a legal framework (Kellmeyer, 2021). Thus, combinations of VR and BCIs will require their own careful analysis, privacy regulations, and protections from manipulation. The latter could be achieved by setting a requirement to demonstrate alternative paths and action possibilities in the virtual world.

4. Principles for the ethical use of educational VR, AR, and MR

To summarize the solutions developed in the previous sections, four principles for the ethical utilization of VR, AR, and MR are presented in the following sections. For a concise summary, see Table 1.

4.1. VR should only be used for suitable learning tasks

Based on empirical findings described above and models such as the CAMIL, it becomes apparent that VR should only be used in situations in which the specific advantages offered by this technology can be harnessed (see Skulmowski & Xu, 2022). It is important to inform educators about the fact that VR has certain strengths, but cannot be used as a "cure-all." The relevant knowledge on how to engage with immersive environments has been called immersive literacy by Steed et al. (2023) and it may be worthwhile to consider the development of specific training programs for educators focusing on this aspect.

For instructional scenarios concerned with learning facts and concepts, traditional methods or other digital tools can be equally useful as VR and may not induce as much cognitive load (Buchner et al., 2022; Mayer et al., 2022). Research suggests that AR may be a less distracting alternative, at least judging from the positive results of a meta-analysis (Garzón et al., 2019); but see also Buchner and Kerres (2023), for a critical review of the quality of educational AR research. An important implication for fields such as teacher training is that technologies such as VR and AR should not simply be lumped together due to their superficial similarities, but rather need to be presented as educational methods with their own advantages and drawbacks. By improving teachers' and students' knowledge regarding the suitability of VR for various learning tasks, learning can be optimized, which should be considered an ethical duty of educators. Furthermore, ways of optimizing the design of realistic visualizations should be investigated, such as using realistic details to communicate relevant and meaningful information (e.g., Skulmowski, 2023).

4.2. Alternatives for low spatial ability learners and cybersickness need to be provided

As I discussed above, some properties and effects of VR and realism severely limit which learners can utilize these technologies. Learners with low spatial abilities are likely to be overburdened by rich detail and complex spatial arrangements in three dimensions (e.g., Huk, 2006). Learners prone to cybersickness will not be able to immerse themselves in a virtual world for a long period of time (or even not at all) using a head-mounted display.

For both of these groups of learners, appropriate alternatives must be provided to ensure equal access to education. Educators should monitor these aspects and identify learners requiring different instructional methods. For instance, AR induces cybersickness less strongly than VR head-mounted displays (e.g., Jensen & Konradsen, 2018; Moro et al., 2017), providing an alternative for some educational VR uses. Furthermore, strongly detailed and complex learning materials can be substituted using more simplified versions that are easier to process for learners with low spatial abilities. Again, educators need to be informed regarding these issues and how to solve them.

4.3. Algorithms that preserve learners' privacy should be used

As outlined above, the rich data that can be collected using VR may be regarded as a threat to learners' privacy. To solve this problem, solutions beyond data protection legislation exist. Using certain algorithms, the data collected using VR (and eye tracking) can be modified to protect users' privacy (Bozkir et al., 2019, 2020, 2021). Thus, by using such an algorithm, it may not be necessary to entirely avoid the use of an eye-tracking functionality if there is concern regarding data protection.

It should be noted that ubiquitous technologies such as smartphones already may be used in ways that threaten users' privacy. However, the data that can be collected using VR is significantly richer (especially when combined with eye tracking and other sensor data) and may provide even greater insights into learners' abilities, attitudes, and development.

Table 1
The table summarizes the four principles developed in this article, together with the problems they are concerned with, negative consequences that could arise from these problems, and suggested solutions.

Principle	Problem	Negative consequences	Solutions
Ensure suitability	VR may not be optimal for the presentation of all types of knowledge	VR may be unnecessary in some situations, hindering learning	Increase knowledge and literacy concerning VR in educators and learners
Low spatial ability learners and cybersickness	Realism can be detrimental for learners with low spatial ability, VR may be unusable for learners prone to cybersickness	Some learners may not be able to use or benefit from realism or VR	Provide alternatives, consider spatial ability tests
Preserve privacy	VR technology can be used to collect detailed data allowing to construct precise profiles of learners	Without data protection laws and data anonymization, data could be used to learners' disadvantage	Informed consent for data collection, privacy legislation, anonymization of data using algorithms
Value autonomy	VR and realism can be persuasive and may be used to manipulate learners	Learners can be misled and made to believe false information	Learners should have the option to lower the level of realism to be able to keep a critical distance, simulations should include alternative pathways

4.4. Learners' autonomy needs to be considered

Several developments will further blur the lines between the virtual and physical world in the future. The ever-increasing computing power of VR hardware will be able to render even more convincing visuals with minute details, and new input devices and interaction techniques will allow an even more immersive experience. This powerful technology has the potential to be abused for manipulative purposes, such as generating false memories (Slater et al., 2020) or creating convincing and memorable experiences around false or misleading information. In particular, we currently do not know whether experiences had in VR may be corrected later, posing a challenge for educators wishing to utilize compelling virtual experiences that may turn out to be factually inaccurate at a later time.

These and other problems summarized above pose a challenge for learners' autonomy, as their ability to critically reflect on immediate experiences they encounter in the virtual world may be diminished. Although traditional media can also be used to persuade and manipulate, based on research suggesting that VR is particularly effective for experiential learning (Makransky & Petersen, 2021), VR may have a greater impact than other technologies and thus requires a different set of guidelines.

As I argued above based on the suggestion of Slater et al. (2020), learners should have the option to lower the level of realism while learning in VR as a safeguard. The emerging possibilities of generative artificial intelligence to generate virtual environments in real-time without human oversight further support this requirement and may lead to additional ethical issues in the future.

5. Conclusion

The application of VR and realism ethics to educational settings acts as a magnifying glass, highlighting several urgent problems of these technologies. Previous ethical analyses have argued that VR can be misused to manipulate, suffers from privacy issues, and may result in negative health effects. Regarding learning, the high level of realism found in most VR environments can have divergent effects based on learners' spatial ability, requiring consideration and possibly even spatial ability tests. Due to the ability of VR to provide learners with entire virtual experiences, particular care must be taken to prevent a manipulative use. Previous suggestions include an option to reduce the level of realism (Slater et al., 2020), but it may be necessary to include such safeguards on the content level as well, requiring virtual experiences to offer a variety of outcomes to restore autonomy. Allowing children and vulnerable groups the regular use of VR is ethically doubtful if there is a lack of data protection regulations and informed consent.

It is important to note that previous technologies, such as Internet cookies and smartphone-based data collection, pose similar problems for people's autonomy and privacy. However, almost all of these known negative effects of technology can be strongly potentiated using VR technology, either by accident or by design. Thus, the use of educational VR technology currently demands a high awareness from teachers, parents, and students. In an ideal world, they should be sufficiently informed about advantages and disadvantages to make reasonable decisions, for instance by reading the privacy policies of the products they use. However, a better alternative would be to develop standards for educational VR that keep learners' autonomy and privacy intact. This paper is not meant as an argument against the use of educational VR in its current form, but rather as an overview of negative effects that may ultimately damage the reputation and acceptance of educational VR, thereby potentially depriving learners of its great potential. With better (and preferably international) standards, many ethical issues of educational VR could be solved.

Future fields of research should include studies on how the strong impressions that VR can leave on learners may be corrected if the previously presented information have been found to contain inaccuracies. The use of AI content creation without human oversight may be inappropriate for educational use as there would be no guarantee that young children and teenagers would not be confronted with inappropriate or even traumatizing depictions. Lastly, the combination of VR and BCIs may further reduce autonomy and will require a closer examination as soon as more use cases of this combination have been established.

In conclusion, the autonomy-conserving utilization of realistic virtual environments requires societal awareness, stringent data protection legislation, methods of user control to avoid manipulation, as well as informed consent. As soon as the challenges outlined in this paper have been overcome sufficiently, realism and VR can provide several significant opportunities for education.

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List of acronyms

AI	Artificial intelligence
AR	Augmented reality
BCI	Brain-computer interface
CAMIL	cognitive affective model of immersive learning
MR	Mixed reality
STEM	Science, technology, engineering, and mathematics
VR	Virtual reality

References

Adams, L. C., Busch, F., Truhn, D., Makowski, M. R., Aerts, H. J., & Bressem, K. K. (2023). What does DALL-E 2 know about radiology? *Journal of Medical Internet Research, 25*, Article e43110.

Adhanom, I. B., MacNeilage, P., & Folmer, E. (2023). Eye tracking in virtual reality: A broad review of applications and challenges. *Virtual Reality*, 1–24. https://doi.org/10.1007/s10055-022-00738-z

Bailenson, J. N., Yee, N., Merget, D., & Schroeder, R. (2006). The effect of behavioral realism and form realism of real-time avatar faces on verbal disclosure, nonverbal disclosure, emotion recognition, and copresence in dyadic interaction. *Presence: Teleoperators and Virtual Environments, 15*(4), 359–372.

Berney, S., Bétrancourt, M., Molinari, G., & Hoyek, N. (2015). How spatial abilities and dynamic visualizations interplay when learning functional anatomy with 3D anatomical models. *Anatomical Sciences Education, 8*(5), 452–462.

Bozkir, E., Geisler, D., & Kasneci, E. (2019). Person independent, privacy preserving, and real time assessment of cognitive load using eye tracking in a virtual reality setup. In *2019 IEEE conference on virtual Reality and 3D user interfaces (VR)* (pp. 1834–1837). IEEE.

Bozkir, E., Günlü, O., Fuhl, W., Schaefer, R. F., & Kasneci, E. (2021). Differential privacy for eye tracking with temporal correlations. *PLoS One, 16*(8), Article e0255979. https://doi.org/10.1371/journal.pone.0255979

Bozkir, E., Ünal, A. B., Akgün, M., Kasneci, E., & Pfeifer, N. (2020). Privacy preserving gaze estimation using synthetic images via a randomized encoding based framework. In *ACM symposium on eye tracking Research and applications* (pp. 1–5).

Buchner, J., Buntins, K., & Kerres, M. (2022). The impact of augmented reality on cognitive load and performance: A systematic review. *Journal of Computer Assisted Learning, 38*(1), 285–303.

Buchner, J., & Kerres, M. (2023). Media comparison studies dominate comparative research on augmented reality in education. *Computers & Education, 195*, Article 104711.

Castner, N., Appel, T., Eder, T., Richter, J., Scheiter, K., Keutel, C., … Kasneci, E. (2020). Pupil diameter differentiates expertise in dental radiography visual search. *PLoS One, 15*(5), Article e0223941. https://doi.org/10.1371/journal.pone.0223941

Cheng, K. H. (2022). Teachers' perceptions of exploiting immersive virtual field trips for learning in primary education. *Journal of Research on Technology in Education, 54*(3), 438–455.

Dalgarno, B., & Lee, M. J. (2010). What are the learning affordances of 3-D virtual environments? *British Journal of Educational Technology, 41*(1), 10–32.

Dekker, S., Lee, N. C., Howard-Jones, P., & Jolles, J. (2012). Neuromyths in education: Prevalence and predictors of misconceptions among teachers. *Frontiers in Psychology, 3*, 429. https://doi.org/10.3389/fpsyg.2012.00429

Dotsch, R., & Wigboldus, D. H. (2008). Virtual prejudice. *Journal of Experimental Social Psychology, 44*(4), 1194–1198.

Dubovi, I. (2022). Cognitive and emotional engagement while learning with VR: The perspective of multimodal methodology. *Computers & Education, 183*, Article 104495.

Dündar, S., & Gündüz, N. (2016). Misconceptions regarding the brain: The neuromyths of preservice teachers. *Mind, Brain, and Education, 10*(4), 212–232.

Dwyer, F. M., Jr. (1967). The relative effectiveness of varied visual illustrations in complementing programed instruction. *The Journal of Experimental Education, 36*, 34–42.

Dwyer, F. M., Jr. (1969). The effect of varying the amount of realistic detail in visual illustrations designed to complement programmed instruction. *Programmed Learning & Educational Technology, 6*, 147–153.

Falcao, C., Lemos, A. C., & Soares, M. (2015). Evaluation of natural user interface: A usability study based on the leap motion device. *Procedia Manufacturing, 3*, 5490–5495.

Friedrich, O., Racine, E., Steinert, S., Pömsl, J., & Jox, R. J. (2021). An analysis of the impact of brain-computer interfaces on autonomy. *Neuroethics, 14*(1), 17–29.

Frolov, S., Hinz, T., Raue, F., Hees, J., & Dengel, A. (2021). Adversarial text-to-image synthesis: A review. *Neural Networks, 144*, 187–209.

Gao, H., Hasenbein, L., Bozkir, E., Göllner, R., & Kasneci, E. (2022). Exploring gender differences in computational thinking learning in a VR classroom: Developing machine learning models using eye-tracking data and explaining the models. *International Journal of Artificial Intelligence in Education*, 1–26. https://doi.org/10.1007/s40593-022-00316-z

Gao, H., & Kasneci, E. (2022). Eye-tracking-based prediction of user experience in VR locomotion using machine learning. *Computer Graphics Forum, 41*, 589–599. https://doi.org/10.1111/cgf.14703

Garzón, J., Pavón, J., & Baldiris, S. (2019). Systematic review and meta-analysis of augmented reality in educational settings. *Virtual Reality, 23*(4), 447–459.

Goldberg, P., Sümer, Ö., Stürmer, K., Wagner, W., Göllner, R., Gerjets, P., … Trautwein, U. (2021). Attentive or not? Toward a machine learning approach to assessing students' visible engagement in classroom instruction. *Educational Psychology Review, 33*, 27–49.

Halbig, A., & Latoschik, M. E. (2021). A systematic review of physiological measurements, factors, methods, and applications in virtual reality. *Frontiers in Virtual Reality, 2*, Article 694567. https://doi.org/10.3389/frvir.2021.694567

Han, I. (2021). Immersive virtual field trips and elementary students' perceptions. *British Journal of Educational Technology, 52*(1), 179–195.

Hughes, B., Sullivan, K. A., & Gilmore, L. (2020). Why do teachers believe educational neuromyths? *Trends in Neuroscience and Education, 21*, Article 100145.

Huk, T. (2006). Who benefits from learning with 3D models? The case of spatial ability. *Journal of Computer Assisted Learning, 22*, 392–404.

Hwang, G. J., Xie, H., Wah, B. W., & Gašević, D. (2020). Vision, challenges, roles and research issues of Artificial Intelligence in Education. *Computers & Education: Artificial Intelligence, 1*, Article 100001. https://doi.org/10.1016/j.caeai.2020.100001

Insel, T. R. (2017). Digital phenotyping: Technology for a new science of behavior. *JAMA, 318*(13), 1215–1216.

Jensen, L., & Konradsen, F. (2018). A review of the use of virtual reality head-mounted displays in education and training. *Education and Information Technologies, 23*, 1515–1529.

Kellmeyer, P. (2021). Big brain data: On the responsible use of brain data from clinical and consumer-directed neurotechnological devices. *Neuroethics, 14*(1), 83–98.

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

Köchling, A., & Wehner, M. C. (2020). Discriminated by an algorithm: A systematic review of discrimination and fairness by algorithmic decision-making in the context of HR recruitment and HR development. *Business Research, 13*(3), 795–848.

Kyrlitsias, C., & Michael-Grigoriou, D. (2018). Asch conformity experiment using immersive virtual reality. *Computer Animations and Virtual Worlds, 29*(5), Article e1804.

LaViola, J., Jr. (2000). A discussion of cybersickness in virtual environments. *ACM SIGCHI Bulletin, 32*, 47–56.

Lee, E. A. L., & Wong, K. W. (2014). Learning with desktop virtual reality: Low spatial ability learners are more positively affected. *Computers & Education, 79*, 49–58.

Lemmens, J. S., Simon, M., & Sumter, S. R. (2022). Fear and loathing in VR: the emotional and physiological effects of immersive games. *Virtual Reality, 26*(1), 223–234.

Makransky, G., & Petersen, G. B. (2021). The cognitive affective model of immersive learning (CAMIL): A theoretical research-based model of learning in immersive virtual reality. *Educational Psychology Review, 33*(3), 937–958.

Makransky, G., Terkildsen, T. S., & Mayer, R. E. (2019). Adding immersive virtual reality to a science lab simulation causes more presence but less learning. *Learning and Instruction, 60*, 225–236.

Markowitz, D. M., & Bailenson, J. N. (2021). Virtual reality and the psychology of climate change. *Current Opinion in Psychology, 42*, 60–65.

Mayer, R. E., Makransky, G., & Parong, J. (2022). The promise and pitfalls of learning in immersive virtual reality. *International Journal of Human-Computer Interaction*, 1–10. https://doi.org/10.1080/10447318.2022.2108563

McCormack, J., Cruz Gambardella, C., Rajcic, N., Krol, S. J., Llano, M. T., & Yang, M. (2023). Is writing prompts really making art?. In *Artificial intelligence in music, sound, Art and design: 12th international conference* (pp. 196–211). Cham: Springer Nature Switzerland. *EvoMUSART 2023, Held as Part of EvoStar 2023, Brno, Czech Republic, April 12–14, 2023, Proceedings*.

Mercer, T. G., Kythreotis, A. P., Harwood, J., Robinson, Z. P., George, S. M., Sands, D., … Sims, T. (2022). The benefits of virtual fieldtrips for future-proofing geography teaching and learning. *Journal of Geography in Higher Education*, 1–9.

Moro, C., Štromberga, Z., Raikos, A., & Stirling, A. (2017). The effectiveness of virtual and augmented reality in health sciences and medical anatomy. *Anatomical Sciences Education, 10*(6), 549–559.

O'Brolcháin, F., Jacquemard, T., Monaghan, D., O'Connor, N., Novitzky, P., & Gordijn, B. (2016). The convergence of virtual reality and social networks: Threats to privacy and autonomy. *Science and Engineering Ethics, 22*(1), 1–29.

Onnela, J. P. (2021). Opportunities and challenges in the collection and analysis of digital phenotyping data. *Neuropsychopharmacology, 46*(1), 45–54.

Petersen, G. B., Klingenberg, S., Mayer, R. E., & Makransky, G. (2020). The virtual field trip: Investigating how to optimize immersive virtual learning in climate change education. *British Journal of Educational Technology, 51*(6), 2099–2115.

Pfeuffer, K., Geiger, M. J., Prange, S., Mecke, L., Buschek, D., & Alt, F. (2019). Behavioural biometrics in vr: Identifying people from body motion and relations in virtual reality. In *Proceedings of the 2019 CHI Conference on human Factors in computing systems* (pp. 1–12).

Prinz, A., Kollmer, J., Flick, L., Renkl, A., & Eitel, A. (2022). Refuting student teachers' misconceptions about multimedia learning. *Instructional Science, 50*(1), 89–110.

Quaiser-Pohl, C. (2003). The mental cutting test "Schnitte" and the picture rotation test-two new measures to assess spatial ability. *International Journal of Testing, 3*(3), 219–231.

Rappa, N. A., Ledger, S., Teo, T., Wai Wong, K., Power, B., & Hilliard, B. (2022). The use of eye tracking technology to explore learning and performance within virtual reality and mixed reality settings: A scoping review. *Interactive Learning Environments, 30*(7), 1338–1350.

Reilly, D., Neumann, D. L., & Andrews, G. (2017). Gender differences in spatial ability: Implications for STEM education and approaches to reducing the gender gap for parents and educators. In *Visual-spatial ability in STEM education* (pp. 195–224). Cham: Springer.

Rieber, L. P. (1994). *Computers, graphics, and learning*. Madison, Wisconsin: Brown & Benchmark.

Shadiev, R., & Li, D. (2022). A review study on eye-tracking technology usage in immersive virtual reality learning environments. *Computers & Education, 196*, Article 104681.

Shadiev, R., Sintawati, W., & Yu, J. (2022). Developing intercultural competence through drone-assisted virtual field trips while adapting to pandemic times. *Journal of Research on Technology in Education*, 1–24. https://doi.org/10.1080/15391523.2022.2067797

Sharma, K., Giannakos, M., & Dillenbourg, P. (2020). Eye-tracking and artificial intelligence to enhance motivation and learning. *Smart Learning Environments, 7*(13), 1–19. https://doi.org/10.1186/s40561-020-00122-x

Skulmowski, A. (2022). Is there an optimum of realism in computer-generated instructional visualizations? *Education and Information Technologies, 27*, 10309–10326.

Skulmowski, A. (2023). Shape distinctness and segmentation benefit learning from realistic visualizations, while dimensionality and perspective play a minor role. *Computers & Education: X Reality, 2*, Article 100015. https://doi.org/10.1016/j.cexr.2023.100015

Skulmowski, A., Nebel, S., Remmele, M., & Rey, G. D. (2022). Is a preference for realism really naive after all? A cognitive model of learning with realistic visualizations. *Educational Psychology Review, 34*, 649–675.

Skulmowski, A., & Rey, G. D. (2021). Visualizing pathogens: Disfluent shapes of pathogens increase their perceived complexity and danger while realism and disfluency boost the credibility of visualizations. *Human Behavior and Emerging Technologies, 3*, 316–323.

Skulmowski, A., & Xu, K. M. (2022). Understanding cognitive load in digital and online learning: A new perspective on extraneous cognitive load. *Educational Psychology Review, 34*, 171–196.

Slater, M., Gonzalez-Liencres, C., Haggard, P., Vinkers, C., Gregory-Clarke, R., Jelley, S., … Silver, J. (2020). The ethics of realism in virtual and augmented reality. *Frontiers in Virtual Reality, 1*, 1. https://doi.org/10.3389/frvir.2020.00001

Slater, M., Khanna, P., Mortensen, J., & Yu, I. (2009). Visual realism enhances realistic response in an immersive virtual environment. *IEEE Computer Graphics and Applications, 29*, 76–84.

Smallman, H. S., & St. John, M. (2005). Naive realism: Misplaced faith in realistic displays. *Ergonomics in Design, 13*, 6–13.

Souchet, A. D., Philippe, S., Lourdeaux, D., & Leroy, L. (2022). Measuring visual fatigue and cognitive load via eye tracking while learning with virtual reality head-mounted displays: A review. *International Journal of Human-Computer Interaction, 38*(9), 801–824.

Spiegel, J. S. (2018). The ethics of virtual reality technology: Social hazards and public policy recommendations. *Science and Engineering Ethics, 24*(5), 1537–1550.

Steed, A., Archer, D., Izzouzi, L., Numan, N., Shapiro, K., Swapp, D., … Lindeman, R. (2023). Immersive competence and immersive literacy: Exploring how users learn about immersive experiences. *Frontiers in Virtual Reality, 4*, Article 1129242. https://doi.org/10.3389/frvir.2023.1129242

Tardif, E., Doudin, P. A., & Meylan, N. (2015). Neuromyths among teachers and student teachers. *Mind, Brain, and Education, 9*(1), 50–59.

Tian, F., Hua, M., Zhang, W., Li, Y., & Yang, X. (2021). Emotional arousal in 2D versus 3D virtual reality environments. *PLOS ONE, 16*(9), Article e0256211. https://doi.org/10.1371/journal.pone.0256211.

Tzuriel, D., & Egozi, G. (2010). Gender differences in spatial ability of young children: The effects of training and processing strategies. *Child Development, 81*(5), 1417–1430.

Vrontis, D., Christofi, M., Pereira, V., Tarba, S., Makrides, A., & Trichina, E. (2022). Artificial intelligence, robotics, advanced technologies and human resource management: A systematic review. *International Journal of Human Resource Management, 33*(6), 1237–1266.

Zhao, J., Sensibaugh, T., Bodenheimer, B., McNamara, T. P., Nazareth, A., Newcombe, N., … Klippel, A. (2020). Desktop versus immersive virtual environments: Effects on spatial learning. *Spatial Cognition and Computation, 20*(4), 328–363.

Zhao, J., Wallgrün, J. O., Sajjadi, P., LaFemina, P., Lim, K. Y., Springer, J. P., & Klippel, A. (2022). Longitudinal effects in the effectiveness of educational virtual field trips. *Journal of Educational Computing Research, 60*(4), 1008–1034.