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ENHANCING GEOGRAPHY EDUCATION THROUGH VIRTUAL REALITY: EXPLORING PEDAGOGICAL AND TECHNOLOGICAL PRINCIPLES

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ABSTRACT

The new educational content framework Skola2030, which was implemented from 2020 to 2023 in Latvia, made it possible to improve the teaching of geography at the secondary level in order to deepen students' understanding of the intricate relationships between natural environments and human activities. All traditional educational tools, such as textbooks, infographics, movies, maps, and simulations focusing on the movement of plate tectonics, are available to students. Still, they address only a small portion of the complex internal operations. Textbooks may provide simplified diagrams of volcanoes that do not accurately portray their many characteristics, and videos showing volcanic disasters could misinterpret the true nature of volcanic eruptions. There are also examples when simulations, as well as cartographic resources, just disregard many unique features of some types of volcanoes, overlooking the diverse attributes of different volcano types, concentrating merely on their geographical occurrences. This well-designed education model allows students to carefully explore a vast number of such features as part of a useful learning experience. This can help in fostering a deep awareness of internal processes and their real-world ramifications.

The study question focuses on the educational and technological principles needed to create an interactive learning tool for comparing various types of volcanoes in a virtual reality setting. These concepts were identified through a systematic literature review. The established principles can be used as recommendations for developing interactive learning aids to compare different types of volcanoes or to assess similar educational resources.

Keywords: *education technologies, geography education, learning experience, technology enhanced learning, virtual reality.*

Introduction

The rapid development of educational technologies and the potential to integrate virtual reality technologies (VR) into the learning process have marked the necessary changes in the methodology of teaching subjects (Hu-Au & Lee, 2017; Kavanagh et al., 2017). Historically seen as an emerging technology for over six decades, VR's potential in education has become increasingly tangible in the last ten years (Wohlgenannt et al., 2020; Allcoat et al., 2021), paralleling advancements in technology and pedagogical approaches (Hu-Au & Lee, 2017). When introducing the new education program Skola2030, the geography subject emphasizes the need to visualize the processes taking place on Earth (Skola2030, 2019) in order to achieve the goals set in the educational standard of both elementary schools (Latvijas Vēstnesis, 2018, 249) and secondary schools (Latvijas Vēstnesis, 2019, 197). The achievable results of the educational curriculum Latvijas Vēstnesis, 2019, 197) foresee a practical, experience-based learning process, the aim of which is to deepen students' understanding of complex and abstract natural processes. However, it is not feasible to observe all the topics and processes covered in the high school geography course in Latvia or to create a learning experience based on these processes. Virtual Reality (VR) technologies offer a unique opportunity for students to gain the necessary experience by depicting processes and phenomena that, without technology, would be logistically challenging, expensive, or impossible due to security concerns, such as visiting the historic Robben Island prison in South Africa or witnessing the construction of the Statue of Liberty in New York (Google Arts & Culture, n. d.).

In order to judge the possibilities of VR for providing a meaningful learning process, it is necessary to define the concept of "virtual reality" and what essential elements characterize it. Virtual reality is a computer graphics simulation close to the real world, characterized by three main elements: presence, interactivity, and immersion (Walsh & Pawlowski, 2002; Rusilo, 2019). These three elements provide an opportunity to "experience" and "learn" with the help of VR technology, creating learning experiences in a VR environment. On the other hand, we can ensure the meaningful use of technology in the learning process by implementing a technology-enchanced learning process, which involves integrating technology with other learning methods (Dror, 2008; Kirkwood & Price, 2014; Dreimane, 2020). This approach creates a learning environment in which technology serves as a tool to support the learning process.

In order to find out the best way for implementing VR technology based teaching tool in secondary school geography eduacation, two research questions were raised:

1. What are the key pedagogical principles that should guide the development of VR-based educational tools to ensure they align with the educational standards and learning outcomes in geography?
2. What technological and GIS (geographic information systems) principles are essential in designing a VR learning tool that accurately represents and simulates the diverse characteristics of different types of volcanoes?

The research draws attention to the limitations of the materials available so far (for example, textbook images and diagrams and video materials), which are not always able to cover the dynamic nature of geological phenomena. The research outlines the principles that should be followed when creating a VR learning tool for the secondary school stage for comparing types of volcanoes, exploring the possibilities of creating a detailed and interactive learning experience that is capable of depicting the characteristic features of different types of volcanoes, and ensuring the meaningful use of technology in the learning process.

Methodology

This study utilizes a systematic literature review methodology (Booth et al., 2016) designed to investigate the principles needed to develop interactive VR learning tools, with a specific emphasis on geography education.

1. **Search strategy:** The literature search was conducted through several well-established academic databases – Google Scholar, Web of Science, Scopus and Primo. These platforms were selected due to their comprehensive coverage of peer-reviewed academic journals and their significance to the field of educational technology research. The search started with broad keywords such as "virtual reality in education." As the search progressed, additional keywords were identified and utilized to refine and expand the search, i.e., "technology-enhanced learning," "VR in geography education," "learning cognitive tools," and "interactive learning environments." Findings and terminologies prevalent in initial search results guided the evolution of search terms. Boolean operators (i.e., "and", "or") were used to combine and refine search terms.

   In order to propose pedagogical principles, literature was searched that covers pedagogical theories and strategies mentioned in the technology-enhanced learning process, such as constructivist theory (Piaget, 1956) and experiential learning (Kolb, 1984). The latest trends in the production of digital teaching materials, multimedia, VR and cartography design were considered to establish the technological and GIS principles.
2. **Selection Criteria:** The studies included in this review were selected based on their focus on VR applications within educational contexts, relevance to enhancing students' understanding, and contributions to pedagogical methods. Most studies published between the 2014 and 2024 were considered to ensure the relevance of the technology discussed. This review included studies focusing on VR applications in education, their relevance to enhancing students' understanding, and empirical evidence supporting their effectiveness. Exclusion criteria included lack of rigorous research methodology, and articles that do not specify computer, VR or technology learning. The final review included articles based on these criteria.
3. **Quality Assessment:** Each source was assessed for quality and relevance based on the rigor of the research methodology, the clarity of the data presentation, and the impact of the findings on the field of educational technology. Quality criteria included research methodology, data presentation, and the study's contribution to educational technology and VR-based learning tools. Articles not meeting the quality threshold were excluded from the final analysis, ensuring a strong understanding of pedagogical and technological principles for VR learning tools.

The systematic approach ensured comprehensive coverage of relevant academic literature, providing a robust foundation for understanding pedagogical and technological principles that need to be applied in the developing of VR learning tools. The review aimed to identify key pedagogical, technological, and geographic information systems (GIS) principles for developing effective VR-based learning tools in geography education. It focused on student engagement, knowledge construction, and experiential learning. Pedagogical and technological requirements were determined, and GIS integration was explored to enhance geographical learning.

Pedagogical Principles for Enhancing VR Learning Experiences in Geography Education

The integration of virtual reality (VR) in the learning process needs to be carefully coordinated with pedagogical principles that promote effective learning and meaningful use of technology. This section will outline key pedagogical principles that need to be followed when designing VR learning experiences. Despite the study's focus on geography learning, developing any learning tool in a VR environment should adhere to pedagogical principles.

According to Piaget (1956) and Kolb (1984), the learning tool must facilitate progress towards a specific, achievable result. The design of a VR learning tool should directly or indirectly link each element to the student's expected result while also incorporating additional elements that heighten the student's interest in the subject (Jonassen, 1992; Bacca-Acosta et al., 2022). When developing a learning tool in a VR environment, it is essential to follow a student-centered approach, which forms the basis of effective learning process design (Mor & Winters, 2007; Aiello et al., 2012). This means that the VR learning tool serves as one of the methods used in the learning process to move towards an achievable result.

A VR learning tool should not only focus on simple knowledge acquisition or a one-dimensional achievable result but also promote higher-level cognitive thinking, problem solving, and synthesis (Jonassen, 1992; Chen & Teh, 2013). Taking into account the complex results that can be achieved in learning the subject of geography (Latvijas Vēstnesis, 2019, 197), the VR teaching tool for learning natural science subjects should be such that it reflects real-world problems and complex natural phenomena, thus allowing students to transfer and apply the newly acquired knowledge in different contexts (Lajoie & Derry, 2013; Hu-Au & Lee, 2017).This method is in line with Kolb's (1984) ideas about experiential learning, which say that solving realistic, difficult problems that are like real-life situations is the best way to learn (Kolb, 1984; Gentry, 1990; Sharlanova, 2004; Fromm el al., 2021). A number of scientific sources (Aiello et al., 2012; Chen & Teh, 2013; Fowler, 2015; Dreimane, 2020) say that constructivism is one of the most important ways to think about how VR can be used to help people learn (Piaget, 1956). Depending on the field of application, constructivism can take on various definitions, but fundamentally, it unifies with the creation or 'construction' of new knowledge from existing knowledge or experiences (Piaget, 1956; Winterbottom & Blake, 2008; Aiello et al., 2012).

By basing the learning process on the constructivist approach (Piaget, 1956), the role of the educator changes from "main source of knowledge" to "coordinator of the learning process," (Holt-Reynolds, 2000) rather supporting students' learning needs. This implies that the educator must adapt the teaching tool to assist the student in self-constructing new knowledge, drawing from their life experiences or prior knowledge (Piaget, 1956; Winterbottom & Blake, 2008), enabling them to consolidate the newly acquired knowledge over time. The VR learning tool should be the next logical step in learning the subject, so that the student can independently move towards the desired result.

In order for the student to be able to independently construct knowledge, according to the framework of constructivist theory (Piaget, 1956), the VR learning tool must include additional elements supporting the learning process, or cognitive tools (Jonassen, 1992; Chen & Teh, 2013). These tools help the learner understand new concepts and build understanding through interaction rather than passive perception (Jonassen, 1992; Mayes, 1992; Huitt & Hummel, 2003). Students can deepen their understanding of a topic by using charts, simulations, and exercises that require data analysis.

In order for an effective learning process to take place, it is essential to provide appropriate feedback for the learning process (Winterbottom & Blake, 2008; Chen & Teh, 2013; Hu-Au & Lee, 2017). Feedback is crucial for both the student and the educator, as it helps them understand what they still need to learn and the extent to which they have achieved the intended learning goal (Winterbottom & Blake, 2008; Chen & Teh, 2013; Hu-Au & Lee, 2017). One can provide feedback by incorporating it into the learning tool, providing immediate feedback on task performance, or utilizing other methods in the learning process, such as teacher feedback (Lee & Wong, 2008; Schartel, 2012). Therefore, it is crucial to consider the method of providing feedback when developing a teaching tool.

This section outlines the main pedagogical principles for creating interactive learning tools in VR environments. When developing a learning tool, it's crucial to start with a single achievable goal that the student can work towards. With the learning tool and the teacher's support, students can also progress towards a more complex, achievable goal, fostering a student-centered approach.

Technological Principles for Enhancing VR Learning Experiences in Geography Education

Creating a comprehensive and meaningful virtual reality (VR) learning experience involves not only the use of pedagogical principles but also technological principles that, when integrated into the learning tool, can facilitate or hinder the student's progress toward the desired outcome (Lee & Wong, 2008). This section will define the main technological principles involved in the development of a VR learning tool. These principles are very important when developing VR learning tools because the VR environment not only supports learning but is also able to meet the student's cognitive abilities and needs.

The VR environment offers a variety of ways to display necessary information, fostering an interactive environment that allows the student to select their preferred method of information acquisition, including images, cartographic material, and audio format

(Dalgarno & Lee, 2010; Chen & Teh, 2013; Fowler, 2015). Understanding the appropriate amount of information to display, given the variety of options available, is crucial to avoid creating an overabundance of information and interactive elements. The visual representation is the main information in the VR environment, so overflowing the visual field with excessive elements can overload their cognitive abilities and interfere with progress towards the achievable result (Mayer, 2008). Effectively placing additional elements in the design of VR learning experiences can serve as cognitive tools (Jonassen, 1992; Mayer, 2008). A successful VR learning tool provides enough interactive elements to engage students without causing cognitive overload. When implementing the technology enhanced learning process in school, the teacher should remember that the teaching material should be based on the results achieved by the student and the construction of knowledge, not on the technological possibilities that a solution can provide (Dror, 2008). Resources such as audio explanations, images, and navigation tools should be intuitively located and easily accessible (Mayer, 2008). According to Lee & Wong (2008) and Chen & Teh (2013), it's crucial to consistently deploy these resources to enhance the duration of information searches and maintain the learning process.

Considering the possibilities offered by the VR environment for displaying information, a VR learning experience should present information in a way that facilitates information acquisition processes without requiring students to split their attention between different methods of information perception. Mayer (2008) mentions that it is best to display visual and audio format in technological teaching aids, in which it is possible to insert a variety of multimedia information – if it is necessary to obtain information from visual aids, then, without dividing attention, it is impossible to read information in text format, so audio information perfectly complements the possibilities of obtaining information. The technical quality of VR information sources also plays an important role (Dalgarno & Lee, 2010; Newman et al., 2022). Clear visuals and high-quality audio are required to maintain a sense of presence in the VR learning experience and bring it as close as possible to the real-life experience.

For the VR experience to be a constructivist-based learning process, students must be able to freely and intuitively use virtual spaces. Navigation is necessary to enable the user to use the required VR environment at their own pace, promoting an active learning process and knowledge construction process (Van Joolingen, 1999; Winterbottom & Blake, 2008; Fowler, 2015). Good navigation promotes spatial sense and facilitates a sense of presence, which is important for experiential learning to occur (Dror, 2008; Chen & Teh, 2013).

This section outlines key technological principles for creating interactive learning tools in VR environments. When integrating these technological principles into the design of VR learning experiences, it is very important to align with the pedagogical principles defined above. It is crucial to fully utilize the pedagogical potential of technology and other teaching methods. Instead, supplementing existing learning materials with appropriate learning methods is needed, enabling students to construct knowledge and progress towards achievable outcomes.

Geographic Information Systems (GIS) principles for Enhancing VR Learning Experiences in Geography Education

When creating a teaching aid with cartographic data in the geographic information systems (GIS) environment, it's crucial to consider the specifics of the topic and subject of the chosen learning tool and adhere to certain principles. The process of incorporating real-world objects or views into a virtual environment demands a detailed and accurate representation to reflect the complexities observed in nature. This precision is required to avoid oversimplification of visual information and authentically present the diverse characteristics and processes (Aiello et al., 2012; Weber et al., 2021; Newman et al., 2022).

Using GIS technologies for the creation of a VR learning tool, it is also necessary to display cartographic data that would reflect the processes of the lithospheric plates and the processes taking place within their boundaries, which would direct the student to the complex achievable result. When representing GIS data, symbols and colors are necessary to promote intuitive understanding and cognitive efficiency (Semmo et al., 2015). Representation is important, as is creating a system of associative symbolism that allows students to grasp information without constant reference to the map legend or symbolism. The challenges also stem from the fundamentals of good cartography and the need to balance the information in the cartographic material without oversaturation (MacEachren, 2004). This means that while we represent related data like lithospheric plate boundaries and volcano locations in a single cartographic material, we do not include geospatial data on the most common plant species, as it lacks a direct connection to endogenous processes.

By following the principles of a realistic environment—apparence and proportions close to reality—it is possible to increase the sense of presence during the VR learning experience (Newman et al., 2022). Displaying objects of true-to-life size within a VR environment facilitates an authentic experience, fostering a deeper connection with the subject matter (Chan et al., 2022). When considering scale, a user of a VR learning experience may struggle to comprehend the actual size of natural objects, even when represented at a real 1:1 scale. Adding a geospatial data layer as a cognitive tool could address this issue by numerically displaying the relative height of an object or the distance between objects.

Selecting the appropriate viewpoint for each object is critical to highlighting natural objects' defining features. By manipulating the viewing angle and perspective, the VR experience can emulate the learner's vantage point if they were observing the features in reality (Newman et al., 2022). This allows for a more profound exploration of the spatial relationship and physical characteristics of the geographical elements.

This section defines the main principles of the GIS environment, outlining the steps to follow when developing a learning tool for geography in a VR environment. To get the best results, it's important to connect the rules of the GIS environment with both the pedagogical rules that tell you how to teach and the technological rules that show you how to use multimedia materials effectively in the VR environment.

Discussion

The literature analysis highlights three principle groups that influence the learning process in the VR environment: five pedagogical principles, four technological principles, and three GIS environment principles. These principles are crucial to adhere to when developing a virtual reality learning tool for comparing volcano types (see Table 1). Despite the focus on a specific geography subject, the principles apply to the development of VR learning tools in other natural science subjects that require the representation of natural objects and cartographic data.

Table 1 Pedagogical, technological and GIS principles to follow when developing a VR learning tool for comparing volcano types

Group	Principle	Explanation
Pedagogical principles	The principle of progress towards the achievable result	The VR learning experience guides the student towards achieving a specific outcome. The main principle when developing a VR learning tool is to focus on the achievable result and how the developed learning tool facilitates the student's path to it.
	The principle of the complex achievable result	The VR learning experience intermediately helps the student move towards the complex achievable result by including elements that contribute to the achievement of higher levels of cognitive thinking.
	The principle of knowledge construction	VR learning experiences enable the construction of knowledge according to constructivist theory (Piaget, 1956).
	The principle of cognitive tools	The design of VR learning experiences incorporates cognitive tools that support the student's learning process.
	The principle of feedback	To ensure a continuous learning process and knowledge transfer, it is essential to provide the student with feedback on their progress towards the achievable result.
Technological principles	The principle of spatial communication	To reduce cognitive load, it is necessary to consistently present sources of additional information.
	The principle of element saturation	To reduce cognitive load, pay attention to the saturation of complementary elements when creating a VR learning experience.
	The principle of information representation	When designing a VR learning experience, it is important to choose information sources that do not require students to divide their attention in order to acquire meaningful information.
	The principle of navigation	Navigation tools enable the student to freely navigate VR learning experience to promote a sense of presence and motivation.
GIS principles	The principle of symbolization	When displaying GIS data, follow the theme of associative symbols and cartographic materials.
	The principle of appropriate scale	To promote the feeling of presence and motivation, natural objects should be depicted in their true size.
	The principle of point of view on the object	The selection of appropriate viewpoints, which represent the characteristic features of the object, ensures the student's progress towards the achievable result.

The methods used in the learning process are constantly changing, integrating more and more new technologies, and the opportunities to meaningfully implement the use of VR technology in the learning process indicate this use. This research has outlined a framework of pedagogical and technological principles that underpin the development of VR learning tools, in the sense that these principles are inseparable and mutually reinforcing.

The educational tool's development in the VR environment places a primary emphasis on adhering to pedagogical principles. These include constructivism, which promotes student-centered principles that help students achieve learning goals and actively build knowledge. The educator's role shifts from "provider of information" to "coordinator of the learning process," supporting students' learning according to these principles.

The technological principles that emerge from VR's possibilities serve pedagogical purposes. The technological element they provide enables the achievement of learning goals, emphasizing that the selection of technology should prioritize the student's needs and learning objectives while also taking into account existing technological possibilities. The process of developing VR educational resources follows pedagogical principles.

Despite being a smaller component of VR learning design, any educational resource that incorporates geospatial or cartographic data can utilize GIS principles. These principles must be linked to the pedagogical and technological principles used in the development of VR learning experiences.

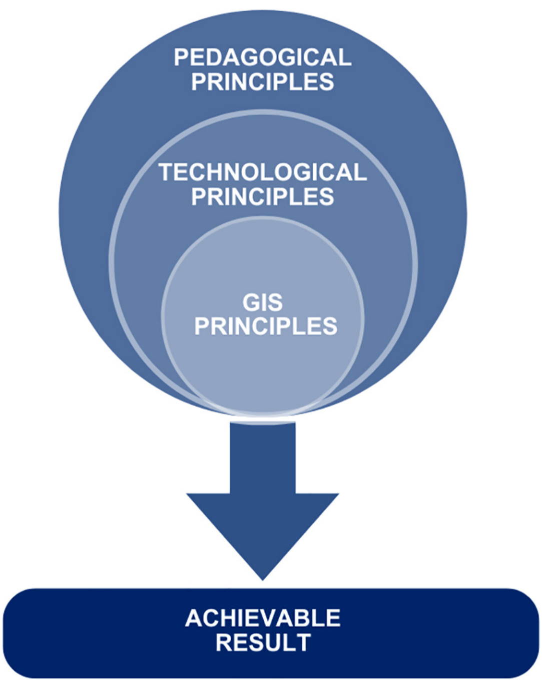

Figure 1 Application of Pedagogical and Technological Principles to Compare Volcano Types of VR Learning Experiences in the Creation Process (Concept made after Tenberga, 2023)

At the heart of any learning tool's development is a focus on the student and his learning needs. The main step in the process is the application of pedagogic principles, which allow students to build knowledge, achieve learning goals, and promote interest and motivation in learning the subject, ultimately leading to a complex and achievable result (see Figure 1). The development of teaching aids primarily revolves around pedagogical principles, with technological principles playing a secondary role, chosen based on their capacity to support pedagogical goals.

Adhering to the conditions and adhering to all three sets of principles can ensure a successful VR learning experience in geography education, facilitating a technology enhanced educational process that meaningfully guides students toward learning goals. In conclusion, the paper not only provides a theoretical basis for the empirical part of the study and the modeling of VR educational tools, but it also serves as a blueprint for future efforts to create a multi-technological learning environment. As future directions of research, how the principles are practically used in the creation of a VR learning tool can be studied not only in the subject of geography but also in other subjects of the natural sciences.

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