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A virtual reality learning environment for high school students to learn the concepts of the electric field and potential: Preliminary results of an intervention study

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Structured Abstract

Background: Virtual reality (VR) is a modern technology that is currently receiving attention in many studies on how it can be used to support learning in schools. It is expected to have various benefits for learning physics. However, little attention has been given to the implementation of VR with a VR headset and to the three-dimensionality of the representations that VR technology can provide.
Purpose: We designed a three-dimensional VR learning environment for Microsoft HoloLens for learning the concepts of the electric field and the electric potential. In the present paper, we show preliminary results of a first intervention study with 26 high school students. With self-developed test instruments, we evaluate the learning progress through the VR intervention. In addition, we explore how the students rate the usability of the VR headset and the VR learning environment.
Sample/Setting: We tested our VR learning environment on two classes of a high school in Bern, Switzerland. We collected and analysed data from 26 students aged 17 to 20 from an intervention study of 75 minutes. The use of the VR learning environment was 15 minutes.
Design and Methods: In a pre- and posttest design, we investigated the effect of the VR learning environment on students' understanding of the electric field and potential. In addition, we asked questions and evaluated the answers regarding the students' experience with the VR headset and the VR learning environment.
Results: Students made significant learning progress by using the VR learning environment: Cohen's $d = .89$. The learning progress was better in items that were similar to those of the VR learning environment, but problems occurred when students were asked to transfer their knowledge to the field of electric charges. Most students considered the technology of the VR headset as good to handle and the VR learning environment to be very interesting and beneficial for their learning process.
Conclusions: Our VR learning environment seems to be suitable for learning, which is shown by the fact that students progressed from the pretest to the posttest. However, further research needs to address the question of whether students learn better with a VR headset than on computers or with paper and pencil.
Keywords: *Virtual reality, visible learning, electric field, electric potential, field vectors, 3D simulations*

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1 Introduction

Virtual reality (VR) is a promising new technology for learning physics (Whitelock et al., 1996; Chen et al., 2004; Li et al., 2021). Pan et al. (2006) defines VR as the use of computer graphics systems in combination with various display devices to provide the effect of immersion in an interactive 3D computer-generated environment. VR can therefore be presented with various displays, such as computers, smartphones, tablets, or with headsets (Radu et al., 2023a). Although the technology of VR headsets is still very basic and not always practical to use, it is expected that it will progress substantially in the coming years (Shim, 2023; Trudeau et al., 2023). The Business Research Company (2022) expects a compound annual growth rate of 36% of VR technology in the global education market. Therefore, it is important to investigate its possible benefits and detriments for instruction in the classroom. Several studies have reported on the development and benefits of VR learning environments or virtual physics games for physics learning (Savage et al., 2010; Olympiou et al., 2013; Grivokostopoulou et al., 2017). Wu et al. (2013) formulated five benefits that VR can provide: it can enable (1) learning content in three-dimensional (3D) perspectives, (2) ubiquitous, collaborative and situated learning, (3) learners' senses of presence, immediacy, and immersion, (4) visualizing the invisible, and (5) bridging formal and informal learning.

One aspect that has received little attention thus far is the 3D representation of physical quantities. There are some studies in different fields, for example, in biology and anatomy, that have compared the learning progress with 3D representations to that with 2D representations and have come to different or ambiguous conclusions (Keller et al., 2006; Huk et al., 2010; He et al., 2022; Krüger et al., 2022; Skulmowski, 2023). Conjectures as to why the use of 3D representation sometimes fails to produce learning gains are learning environments with improper designs (Linn et al., 2011) or cognitive load (Wu et al., 2013), but there is general consensus that the cognitive processes while using VR for learning are poorly understood; thus, further research is needed (Huang et al., 2010; Wu et al., 2013; Chang et al., 2022; Lamb et al., 2022; Radu et al., 2023b). Additionally, the question of whether displaying physical quantities with a VR headset is a promising way to learn has rarely been explored thus far. The reason for this is that headsets are still very expensive and difficult to obtain (Chen et al., 2022; Radu et al., 2023a, 2023b). Strojny and Dużmańska-Misiarczyk (2023) noted that between 2008 and 2018, studies of VR on desktop applications were the most popular, and only since 2019 have studies of VR using portable devices (smartphones, tablets, and headsets) overtaken them. VR headsets are expected to be more immersive but could be more likely to lead to experience fatigue than computer screens (Taxén & Naeve, 2002; Huang et al., 2010). To make a contribution here, we have developed a VR learning environment with which students can learn about the electric field and how it relates to the electric potential. Our learning environment uses three benefits of VR from the list of Wu et al. (2013): Representation in 3D (1), immersion (3), and representation of invisible quantities (4). By using headsets instead of computers, we expect a stronger effect on the items (1) and (3).

2 Research Background

2.1 Virtual reality in physics

Many students consider physics a difficult subject. A major reason is the abstractness of physical quantities and concepts that have to be learned. Students often have problems connecting them to their everyday experience (Winkelmann et al. 2022). According to the well-established cognitive theory of multimedia learning (Mayer, 2002), illustrations and images are important for students' learning process. Human cognition is divided into two different channels for processing information. One channel reacts to verbal information and the other to visual pictures and illustrations. Mayer (2002) formulated eight principles of multimedia learning based on his cognitive theory. The first principle is the multimedia principle, which states that students often learn better when verbal information is accompanied by visual illustrations than when it is accompanied by words alone. However, Mayer & Moreno (1998) formulated the "individual differences principle", which states that multimedia learning is not equally important for all students. Using visual representations has a stronger effect on students with lower prior knowledge of the topic and on students with good spatial imagination. According to Sweller et al. (2003) and Kalyuga (2009), an "expertise reversal effect" can occur, meaning that representations that are beneficial to students with low prior knowledge can be detrimental to students with high prior knowledge. In the case of our topic of the electric field and electric potential, we expect that the vast majority of students have rather low prior knowledge because when they start with this topic in school, these two physical quantities are usually new to them. Neither in school nor in everyday life might they have dealt with them. Therefore, we suppose that visual representations are very important and helpful especially in this topic. VR is a common technology used to represent abstract invisible quantities. Gentner and Stevens (1983) have elaborated the concept of mental models (Rieber, 2009). A mental model is a person's idea of how to explain something. Usually, one thinks of something familiar to explain something new (Rieber, 2009). This is an important technique during the learning process. With a VR headset, we are able to display larger illustrations and to walk through and interact with them, which is not possible on a computer screen or on paper. Moreover, one can display 3D objects much more realistically than on computer screens because only a headset enables stereoscopic viewing, meaning that the view on an object changes when a student moves and changes their position similarly as in reality, which does not happen when you look at something on a computer screen (Shibata, 2002; Strojny & Dużmańska-Misiarczyk, 2023). Therefore, we expect that

VR learning environments realized with headsets will make physics tangible and experienceable and support students in building helpful mental models.

Indeed, many studies have shown that illustrating abstract physical representations with VR simulations can help students learn physical concepts (Dori & Belcher, 2005; Olympiou et al., 2013). Olympiou et al. (2013) have shown that students with lower prior knowledge benefit more from learning with VR than students with higher prior knowledge because the latter are able to create correct mental models on their own. In regard to more difficult tasks, students with higher prior knowledge also benefit from the opportunity to use VR. Kim et al. (2001) have suggested that 3D virtual simulations come closer to the real world because the real world is in 3D and therefore 2D simulations lack reality.

2.2 The electric field and the electric potential

Electric fields describe the interaction between electric charges. Electric charges cause electric fields that surround them and exert forces on other electric charges. The electric field is a vector field, which means that it has a direction and a magnitude at each point in space. Understanding the field concept is fundamental to explaining phenomena in electricity and magnetism (Törnkvist et al., 1993). However, several studies have indicated that learning this basic concept is very challenging (Maloney et al., 2000; Saarelainen et al., 2007). Possible reasons for this might be that the electric field is an abstract quantity with no direct real-life reference, and moreover, it is three-dimensionally spread out in space and therefore difficult to imagine.

Another physical quantity that has been introduced to explain phenomena in electricity is the electric potential. The electric potential is a scalar field quantity, which means that it has no direction, only a magnitude. The potential is also caused by electric charges but is less complex to describe than the electric field. Bagno et al. (2000) have shown that introducing first the electric potential and then the electric field as a change of potential in space is a promising way to better understand the electric field. Heckler and Sayre (2010) have shown that when learning about the electric field followed by the electric potential, the knowledge of vector fields can decrease rapidly. The voltage in electric circuits, where many misconceptions also prevail (Cohen et al., 1983; McDermot & Shaffer, 1992), can also be well described as a difference between two potentials. This makes the electric potential a useful quantity in electricity. Some studies have shown that learning physics concepts more generally with fewer practical examples can lead to a deeper understanding of the concept, making it easier to transfer knowledge to other contexts (Sloutsky et al., 2005; Kaminski et al., 2006).

We expect abstract and invisible field quantities such as the electric potential and the electric field to be excellent concepts to explore using 3D virtual reality. The electric field can be represented by a mathematic formula but also by a visual illustration, such as a vector field plot. Illustrations are much less abstract representations than formulas of the same physical concept. Very often, illustrations provide students with a more concrete introduction to a complex topic (Mayer, 2002). For vector fields such as the electric field, there are two common visual representations: field lines or field vectors. In school, the focus is often on field lines, but there are several problems with this representation. For example, students may think that one line is an isolated entity instead of a representation of the whole field or they do not understand that the electric field as a physical quantity is a vector quantity with magnitude and direction at each point in space (Törnkvist et al., 1993).

The magnitude of the electric field indicates how much the electric potential changes in space. It is possible to describe this concept by a mathematical formula. However, it is presumably easier to understand if the potential is represented graphically, linking the change in space to the slope of a landscape. It is usually advocated to promote the understanding of physical concepts more through qualitative, conceptual illustrations than through mathematical formulas (Forbus, 1997; Squire et al., 2004).

The exchange with various physics teachers from high schools showed that in Switzerland, the electric field is usually taught towards the end of high school, while the electric potential is not taught by all teachers. The electric field in general is a new topic for students that is not grounded in their everyday life. This makes it difficult for students to develop a mental model that is suitable for the new concept. Our VR learning environment might help students connect the electric potential to real world landscapes, something they already know. For example, the electric potential of a positively charged plane could be related to a gable roof of a building, and the potential of a positive point charge could be related to a volcano-like landscape. The electric field might then be linked to the initial acceleration of a ball placed in the landscape. In this way, students might become comfortable with abstract concepts by transferring the same concept from an intuitive context to a less intuitive context according to the concept of mental models (Rieber, 2009). Bagno et al. (2000) have shown that learning concepts in different contexts supports the learning process, while traditional physics teaching divided into different topics leads to a fragmented knowledge structure.

2.3 Research questions of the present study

In the present study, we address two research questions about the 3D VR learning environment:

1. What effect does a 15-minute intervention with our VR learning environment have on students' knowledge about the electric field and potential and their relation?
2. How do students rate the usability of the VR headset and the VR learning environment?

We expected that students would be interested and excited to use a VR learning environment in school because VR technology generally has a good reputation and is considered an exciting technology. Moreover, it has been used very rarely in schools thus far. Due to the expected involvement of students, the several advantages of VR discussed above (e.g., the 3D perspectives, the immersive learning, the visualization of invisible quantities), and the promising results in other studies (Savage et al., 2010; Olympiou et al., 2013; Grivokostopoulou et al., 2017), we expected a considerable learning gain. Because the learning time was limited to 15 minutes of practice, we expected a medium effect size. However, since the VR learning environment may be less impressive than VR experiences created from the VR gaming or entertainment industries, we were not sure whether students would like it or be disappointed after using it. We have also experienced that the handling, such as clicking on holograms, is very unfamiliar to people with little experience with VR technology and that it takes time to become familiar with it.

3 Methods

3.1 The VR learning environment "eFeld"

We have developed a VR learning environment for the Microsoft HoloLens with the game engine Unity 3D. It consists of 18 multiple-choice tasks. Every task shows a landscape of an electric potential. For each landscape, the corresponding vector field has to be identified from six given options. When clicking on a vector field, the VR learning environment directly indicates whether the selection is correct or not. The 3D landscapes are illustrated in blue. Each landscape actually represents a graph of a 2D potential, and the vertical axis shows the magnitude of the potential along the horizontal *x*- and *y*-axes. Locations where the potential is high are illustrated by hills but also by a lighter facet of the blue colour. The students can try three times for each landscape to identify the corresponding vector field. They obtain points when they select the correct solution. They receive more points when they find it on the first try. By this, we want to avoid a trial-and-error strategy with blind guesswork. With the VR headset, they can walk around and look at the landscape of the potential from every side. When they are unsure about the correct solution, they can click on points in the landscape, and one vector is shown on that very position. That might be helpful to find the correct solution, but they will be penalized by the deduction of a small number of points. Figure 1 shows two examples of tasks in the VR learning environment.

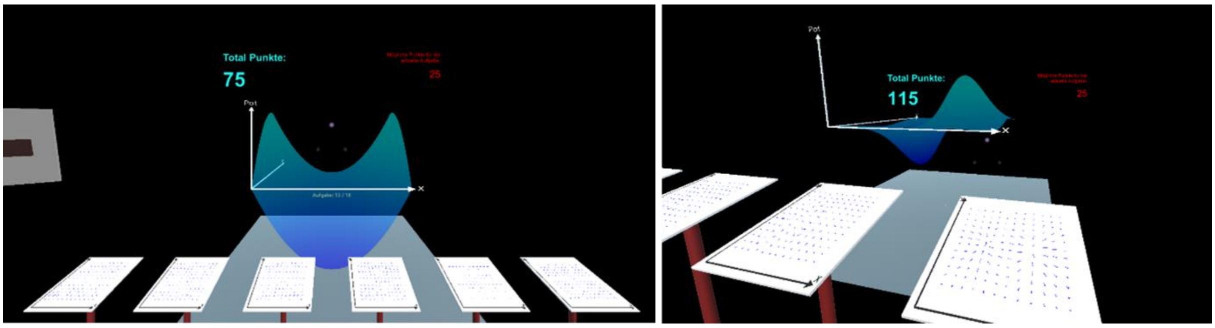


Fig. 1. Two examples of tasks in the VR learning environment. The 3D landscapes in blue are representations of electric potentials. The six white plates in the front show six possibilities of electric fields represented by field vectors, where only one is the correct solution that belongs to the potential.

The VR learning environment "eFeld" is context-free. This means that it can be used not only in the context of electricity but also in other contexts where vector fields are connected to scalar fields in a similar way, for example, in the context of gravity.

3.2 Design and procedure of the present study

We conducted the study with 35 students of two high school classes (ages 17-20; $M = 18.19$) in December 2021 in Bern, Switzerland. We separated the students into four groups due to the limited number of HoloLenses, and they all performed the same intervention. Figure 2 shows two pictures of students wearing HoloLenses and solving exercises. Twenty-six students confirmed that they had taken part seriously and gave consent that we could use their data. The study lasted approximately 70 minutes and took place in German. The procedure of the study is displayed in Fig. 3. At the beginning, the students were introduced to scalar and vector fields, the field vector representation, and the relation between the electric potential and the electric field. After that, they performed a pretest with nine items. Then, they used the VR headset learning environment for 15 minutes, and at the end, they completed the posttest with 13 items. Nine items were identical in the pretest and the posttest. They did not receive feedback or solutions until the very end of the study.

To evaluate students' impression of the HoloLens technology and the VR learning environment, we applied six questions with a four-level Likert scale. Three questions were about the use of the HoloLens, and three were about the VR learning environment. The English translations of the questions are listed in Table 2 in the results section. The original questions in German were integrated into the posttest, which can be found in the appendix.

Fig. 2. Students wearing HoloLenses and using the VR learning environment "eFeld"

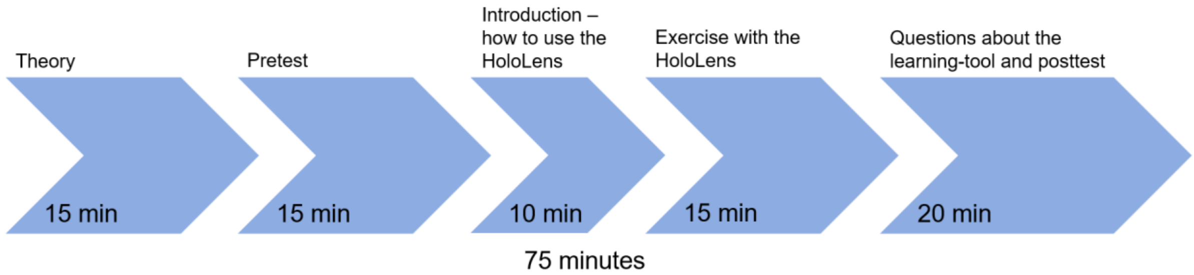


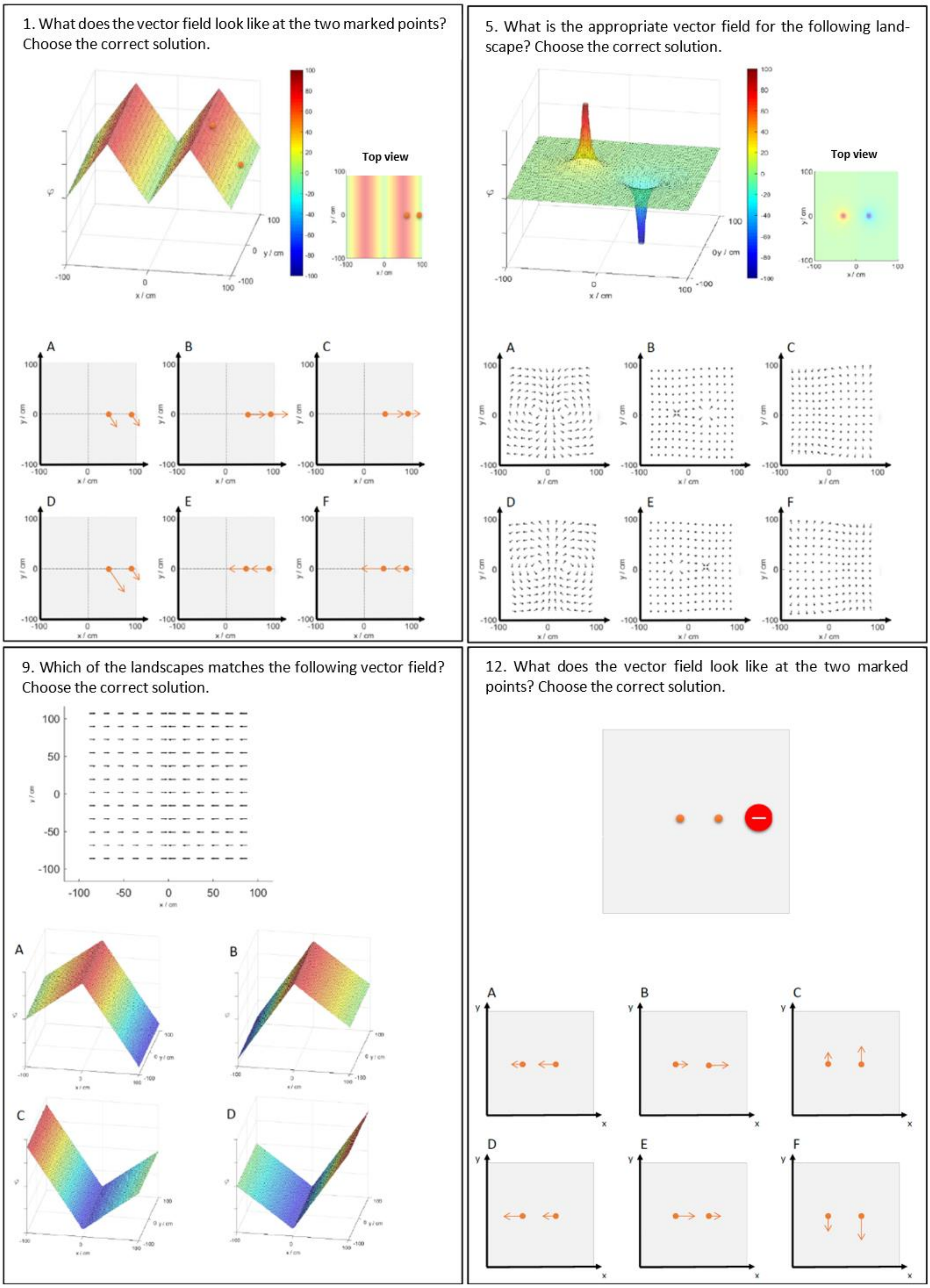
Fig. 3. Procedure and timeline of the study

3.3 Test instruments

In order to answer our first research question, we used a pre- and posttest design to evaluate the learning progress of students. Because there are no available validated test instruments for the present topic, we developed the test instruments ourselves. In a first prestudy with 66 high school students, we applied a test with open questions. Students had to draw field vectors for a given landscape. The goal was to examine what students' typical misconceptions were. We found evidence for six misconceptions that occurred regularly: Vectors pointing in the wrong direction, no variation in the length of the vectors, inverse length of the vectors, linking the length of the vectors to the height of the potential, aligning vectors according to the global maxima and minima, and confusing the front view with the top view of the landscape. Based on these findings, we designed a pre- and posttest in a closed multiple-choice format and different tasks for the VR learning environment. We used the identified misconceptions to create appropriate distractors. The tests were revised and validated by three experts: an experienced physics professor as well as a researcher with a PhD in physics education and a physicist with subject teacher qualifications.

The final version of the posttest, which we applied in the present study, consisted of 13 items, from which a subset of nine items served as the pretest. The idea of having four extra items in the posttest was to get a more fine-grained picture of students' knowledge after the intervention. Due to time constraints and also to reduce testing effects (Richland et al., 2012), we did not include all of them in the pretest. The tests were composed of four different groups of items. One example item from every group in the pretest is shown in Fig. 4. All items in the tests were multiple-choice questions with four to six distractors and one correct solution. In the first group (Items 1-4), a distribution of a potential was given, and the corresponding set of two vectors at two given points in the landscape had to be identified. The second set (Items 5-7) included items where the associated vector field to a given potential had to be determined. In the third group (Items 8-10), a vector field was given, and the related potential had to be selected. In the last group (Items 11-13), one had to find the correct electric field vectors at two points, given a distribution of electric charges instead of a potential. Thus, the electric potential first had to be deduced from the charge distribution. By means of these two items, we wanted to test whether students were able to transfer their knowledge to the context of electric fields of charges. To give them some support, they were shown a representation of the electric potential of a single positive and negative charge.

To determine the reliability of the tests, we calculated Cronbach's alpha (Cronbach, 1951). We obtained α=.63 for the pretest and α=.81 for the posttest. According to Taber (2018), the posttest has an acceptable value (α>.70). The lower value in the pretest might be explained by guessing due to low prior knowledge. As the nine items of the pretest are a subset of the posttest, we are still confident that the test is an adequate measure for our study purpose.



1. What does the vector field look like at the two marked points? Choose the correct solution.

5. What is the appropriate vector field for the following landscape? Choose the correct solution.

9. Which of the landscapes matches the following vector field? Choose the correct solution.

12. What does the vector field look like at the two marked points? Choose the correct solution.

Fig. 4. One example item for each group of our pre- and posttest

The psychometric properties of all items in the pre- and posttest are listed in Table 1. It is mentioned which items in the posttest also appeared in the pretest. For every item, we calculated the parameters item difficulty, item-total correlation, and the item discrimination index. The item discrimination index is the average item score of the upper group minus the average item score of the lower group. Kelley (1939) has argued that the upper and lower groups are the 27% of students with the highest and lowest scores in the overall test.

Tab. 1. Results for the items in the pre- and posttest of 26 students with the parameters item difficulty, item-total correlation, and item discrimination index and desired values (according to Beichner, 1994).

Pretest item	Item group	Difficulty .2-.9	Correlation > .2	Discrimination > .3
1	1	0.15	0.28	0.40
2	1	0.62	0.47	0.86
3	1	0.46	0.29	0.66
4	2	0.50	0.16	0.51
5	2	0.46	0.38	0.86
6	3	0.50	0.43	0.80
7	3	0.46	0.43	0.86
8	4	0.69	0.34	0.71
9	4	0.04	-0.08	0.00
Posttest item				
1 (= 1 in pretest)	1	0.50	0.49	0.86
2 (= 2 in pretest)	1	0.81	0.53	0.50
3	1	0.42	0.46	0.86
4 (= 3 in pretest)	1	0.65	0.56	0.75
5 (= 4 in pretest)	2	0.88	0.40	0.50
6 (= 5 in pretest)	2	0.85	0.72	0.75
7	2	0.77	-0.02	0.00
8 (= 6 in pretest)	3	0.73	0.53	1.00
9 (= 7 in pretest)	3	0.65	0.73	1.00
10	3	0.92	0.56	0.50
11 (= 8 in pretest)	4	0.77	0.52	0.75
12 (= 9 in pretest)	4	0.04	0.05	0.00
13	4	0.35	0.20	0.43

To evaluate the learning progress in our study, we considered the average normalized gain factor $\langle g \rangle$ (Hake, 1998) individually for the different groups of items that were equivalent in the pre- and posttest. This factor is calculated by

$$\langle g \rangle = \frac{\%\langle \text{post} \rangle - \%\langle \text{pre} \rangle}{100 - \%\langle \text{pre} \rangle}$$

Accordingly, a factor of 100% means a maximum possible average gain, while a factor of 0% means that there was no difference between the pre- and posttest. A negative factor would mean a decrease.

4 Results

4.1 Learning gain of the VR intervention

Comparing the answers for the nine identical items in the pre- and posttest, we find that many students made progress during the VR learning environment. The results are shown in Fig. 5. Three students achieved a lower score in the posttest. One student was able to give eight correct answers in the pretest, while nine students had eight correct answers in the posttest. Three students (in the upper left of Fig. 5) did not understand the concept of the electric field until they used the VR learning environment. Comparing the five students with the lowest prior knowledge (0-1 points in the pretest) to the five students with the highest prior knowledge (6-8 points in the pretest), the average normalized gain is rather similar, with values of 49% and 45%, respectively.

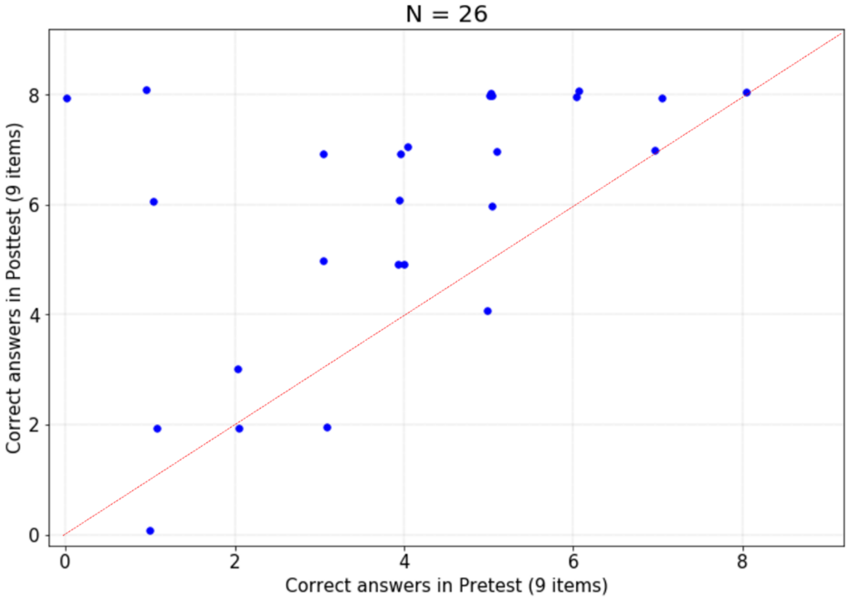


Fig. 5. The dots show the results of students in the pretest (x-axis) and in the posttest (y-axis) for the nine items, which were identical in both tests. Dots above the red line indicate students who performed better in the posttest than in the pretest (20), dots on the red line indicate students who performed equally well in both tests (3), and dots below the red line indicate students who performed worse in the posttest (3).

A look at the results of the individual items shows that students make progress in solving problems that are similar to those in the VR learning environment (Items 4 & 5, ⟨g⟩= 74%). Less progress is made on items that are slightly different from those in the VR learning environment (Items 1-3 and Items 6 & 7, ⟨g⟩= 41%), and almost no progress is found on the last items (Items 8 & 9), where they had to transfer their knowledge to problems with electric charges. In Fig. 6, the results for all items are shown, and in Fig. 7, only the nine items that appeared in both tests with the calculated normalized gain factors ⟨g⟩ for each item group are shown. For Cohen's d measuring the effect size in the VR learning environment intervention, we obtained a value of d = .89.

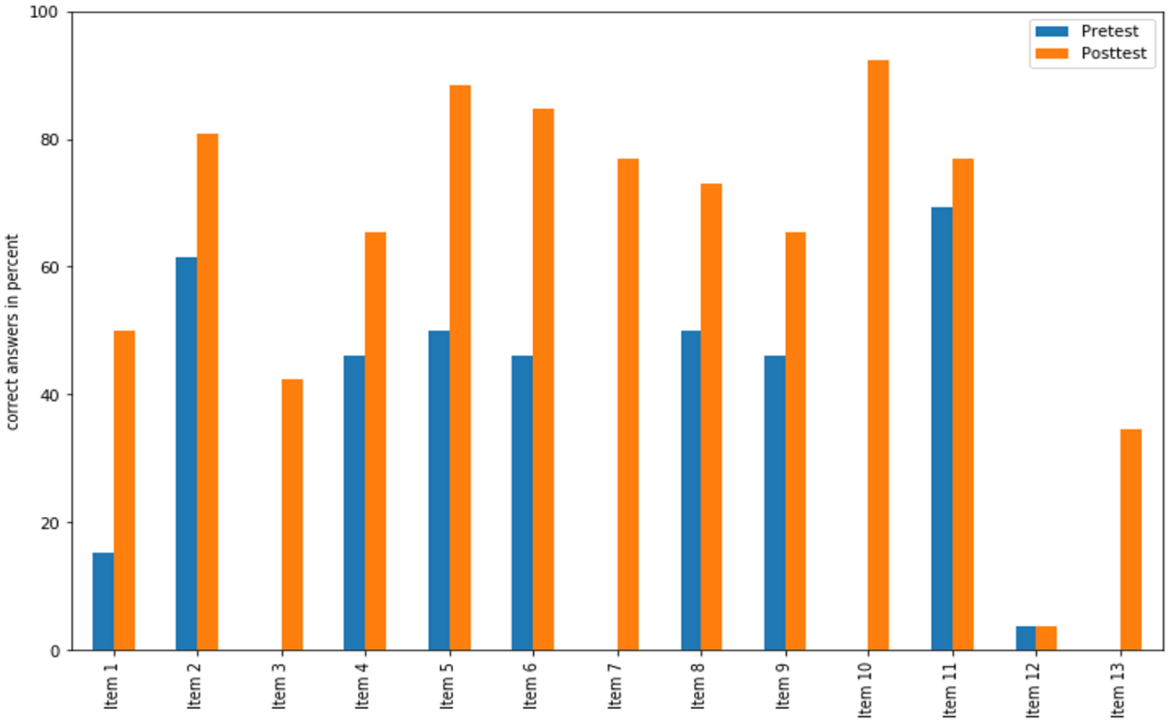


Fig. 6. Number of correct answers in percent for each item

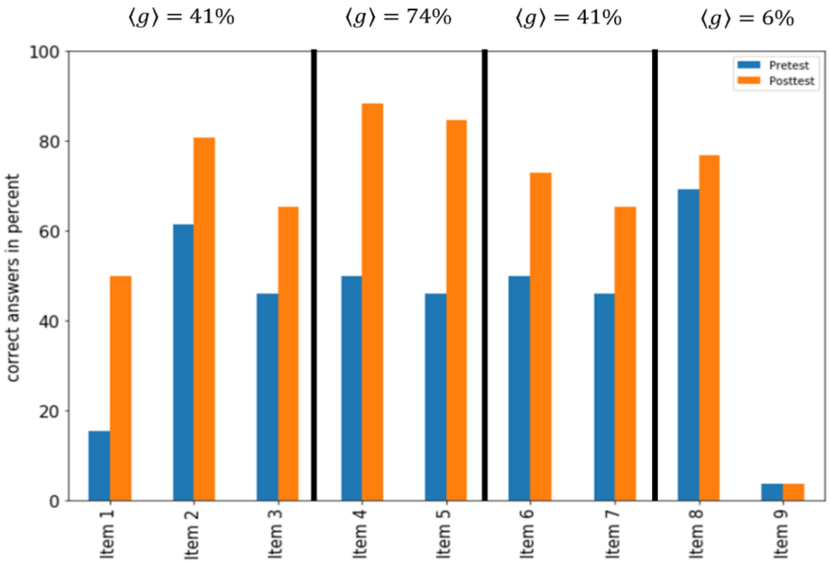


Fig. 7. Progress for each of the nine items, separated into the four groups, that were identical in the pre- and posttest

4.2 Questions about the VR headset and the VR learning environment

Twenty-five students completed the questionnaire about the HoloLens technology and the learning tool. The questions and the distribution of answers results are listed in Table 2. The majority of them are positive. Additionally, in addition to the written questions, many students appeared to be very enthusiastic, and informal feedback about the VR learning environment was positive throughout. Since they were only allowed to use the VR learning environment for 15 minutes, most of them did not finish all tasks and wanted to use the VR learning environment for a longer time. They nearly had to be forced to take off the HoloLens and complete the posttest. There was no oral feedback that they had trouble seeing the holograms correctly or that they could not select the solutions. Once the headsets were on and they started the VR learning environment, everyone was solving the problems independently without the need for assistance.

Tab. 2. Answers of 25 students about their impression after using the VR learning environment.

Questions about the HoloLens technology	bad	rather bad	rather good	good
How did the HoloLens feel on your head?	0	6	15	4
How do you rate the visibility of the holograms during the game?	0	2	11	12
How did you cope with the hand movements during the game?	0	6	8	11
Questions about the VR learning environment	no	rather no	rather yes	yes
Did you find it helpful that you saw the landscapes in three dimensions and not just in a computer?	0	1	4	20
Did you find it helpful that you could walk through the landscapes to view them from all sides?	0	2	3	20
Did you find it helpful to click on points in the landscapes to show individual vectors?	4	3	6	12

5 Discussion and Conclusions

5.1 Discussion

Considering our first research question, the results show that most of the students made substantial learning progress while using the VR learning environment for 15 minutes. This indicates that VR might indeed be a suitable technology to help students understand the relation between the electric field and potential. As in the study by Dori and Belcher (2005), the visual illustration of abstract quantities might have supported the learning process. Moreover, the VR learning environment seems to unfold its potential in a rather short amount of time. With a Cohen's $d = .89$ we obtained a large effect which is higher than we expected. Contrary to the study by Olympiou et al. (2013), in our study, the learning progress through the intervention is not significantly dependent on prior knowledge. Students with a lower score on the pretest experienced similar learning gains on average (49%) as students with a higher score on the pretest (45%). However, the results also show that students have problems transferring knowledge about the relation of electric fields of potentials to the context of electric charges.

The results of the questionnaire used to investigate the second research question show that most students got along well with the HoloLenses and the VR learning environment. However, not all students found it helpful to click on the points in the landscape to view individual vectors. Some told us verbally or wrote next to the question that they never used this opportunity during the exercises in the VR learning environment and therefore could not meaningfully answer the last question of the questionnaire. The part with the opportunity to show an individual vector by clicking on one point in the landscape was also very complex to implement, and the VR learning environment sometimes had problems with the calculation and did not display the vector correctly. For these reasons, we are thinking about removing this implementation from the VR learning environment for future studies to make it more stable.

5.2 Limitations

Although we assume that the representation of the electric potential with a VR headset is a very promising method that is ahead of current technology, there are some technical limitations of our VR learning environment and of VR technology in general that we must mention here. The 3D landscapes of our VR learning environment describe the distribution of a 2D potential, while the third axis is needed to represent the magnitude of the potential. This is a simplification of the real 3D world with its 3D physical quantities. Showing a 3D potential where the magnitude of the potential is represented by colour or brightness would be possible but difficult to illustrate. It would be very difficult to understand the distribution of the potential at once. Another problem is that it is very difficult to illustrate proportionality with colours or brightness. With our VR learning environment, we tried to move one step forwards in representing invisible physics in the real 3D world, but we still face the problem that we cannot illustrate the world as it is.

Another limitation is that we did not systematically collect data on how many tasks students solved and how many they solved correctly during the practice time with the VR learning environment. We kept the time on task constant, which is common in the field (Strojny & Dużmańska-Misiarczyk, 2023) and also consistent with school practice. Some students were able to solve all 18 tasks, but most students had to finish the exercise without solving all tasks. However, since all tasks are of the same type (finding the correct electric field to a given potential), solving more or less tasks did not change the covered content.

Finally, due to the rather small number of students in our study, these preliminary results are limited and have to be corroborated in a larger study.

5.3 Conclusions

Our intervention showed that the three-dimensional VR learning environment can effectively support students in learning about electric field and potential. Although we observed substantial learning in a relatively short learning time, it is yet unclear whether such learning gains could also be achieved by more traditional methods or by VR implemented on a regular computer instead of the headset. In future studies, we plan to focus more on how electric charges create a potential in the theory section at the beginning of the intervention. We also want to evaluate whether using a VR headset is indeed more beneficial than solving the same problems on a computer or with paper and pencil. There is also a need for further validation of the test instruments, considering the reliability of the pretest and items with rather low item-total-correlations (e.g., Items 7 and 12 in the posttest).

Appendices

Appendix 1: Detailed raw data from the present study

Appendix 2: Pretest

Appendix 3: Posttest

Acknowledgements

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