Supporting Conceptual Understanding of the Electric Potential and the Electric Field using Virtual Reality

Roman SCHMID, Andreas VATERLAUS, Andreas LICHTENBERGER

ETH Zurich, Laboratory for Solid State Physics, John-von-Neumann-Weg 9, 8093 Zurich, Switzerland

Abstract. Virtual Reality (VR) is a promising technology for enhancing concept learning in physics. We developed a three-dimensional VR learning environment comprising tasks on electric potentials and fields. In an experimental study with 210 students of the advanced track of the Swiss secondary school, we compared the learning gains when students solved the tasks using the VR environment with a VR headset or with a computer or in a non-VR setting using projections printed on paper. While there was no significant difference between the conditions overall, students with lower spatial abilities showed significantly greater learning gains in the VR headset condition.

Introduction and theoretical framework

There is a general consensus that modern technologies such as virtual reality (VR) and augmented reality (AR) can enhance student learning.[1] Three specific benefits of VR include the ability to present learning content in three-dimensional (3D) perspectives, provide immersive learning experiences, and visualize invisible content.[2] While there are several studies on VR in different fields of science, the effect of 3D representations of physical quantities on learning has received little attention so far. To contribute to this field, we developed a VR learning environment about electric potentials and fields that can be used either with VR headsets or with computers. While visual representations are crucial to learn physics, former studies have emphasized the importance of exploring how the learning process is influenced by the spatial ability of the students.[3] For example, in a study in which two different working systems were explained with computer animations or with spoken text, it has been found that students with higher spatial abilities benefit more from visual learning than students with lower spatial abilities.[4]

Research questions

This study aims to contribute to the question of how VR can support physics learning by using 3D representations with VR headsets and how it is influenced by the students' spatial abilities. Electric potentials and fields were considered a suitable topic due to their spatial nature and invisibility without VR.

Two research questions were addressed:

- Is there a significant benefit regarding the acquisition of conceptual knowledge for students using a VR headset compared to a computer or paper?
- How does spatial ability affect learning gains when learning with visual representations?

Methods and findings

We collected data from 210 students from 14 classes of the advanced track of the Swiss secondary school. All students watched a learning video about electric potentials and fields and then solved a pretest on this topic and a cube comparison test on their spatial abilities.[5] After that, they were randomly divided into three conditions: VR headset, computer and paper. All groups had 15 minutes time to work on 18 tasks in which they hat to match an electric potential to the corresponding electric field from a given set of choices. The tasks were similar in all groups.

However, the representations of the potentials and fields and the immersiveness differed. In the VR headset condition, students experienced 3D virtual visualizations in real space. They could walk through the visualizations and view them from different places and angles. In the computer condition, the same visualizations were displayed as 3D objects on 2D computer screens. Students could rotate and zoom the visualizations using the keyboard or the mouse. In the paper condition, students were presented with two printed static projections that were limited to 2D. Posttests after the intervention were applied to measure the learning gains of the three groups. We used the widely used average normalized gain factor formula.[6]

The results show that students made slightly more progress with VR headsets, $\langle g \rangle = .23$, compared to the computer condition, $\langle g \rangle = .14$, or paper, $\langle g \rangle = .17$. However, an ANOVA revealed no significant differences, $F(2, 203) = .872$, $p = .420$. While the performance on posttest tasks similar to those in the intervention was comparable in all conditions, the VR headset condition showed slight advantages for transfer problems. Regarding students' spatial ability, we found a significant correlation to the learning gain across all conditions ($r = .362$, $p < .001$). Comparing only the students with a spatial ability below the lower quartile, we observed progress only in the VR headset condition, $\langle g \rangle = .18$, while there was practically no improvement in the other two conditions computer, $\langle g \rangle = -.03$, and paper, $\langle g \rangle = .00$, an ANOVA indicated a significant difference between conditions, $F(2, 44) = 3.369$, $p = .044$.

Conclusion

We found that students with high spatial abilities have an advantage in understanding concepts related to the electric potential and field. Our results are in line with findings of previous studies that students with lower spatial abilities may struggle when learning with visual representations.[4] While the VR headsets were not found to be generally more beneficial than computer or paper in our intervention, the more realistic and immersive 3D representations better supported the learning of students with lower spatial ability. Students with higher spatial abilities may rely on simpler representations for comprehension. The potential of VR headsets to support weaker students to learn complex topics in physics with high demands on spatial imagination underlines the importance of further research in this area.

References

[1] F. Li, X. Wang, X. He, L Cheng, Y. Wang, (2021). How augmented reality affected academic achievement in K-12 education: A meta-analysis and thematic analysis. *Interactive Learning Environments* **31**(9) (2021). https://doi.org/10.1080/10494820.2021.2012810

[2] H. K. Wu, S. W. Y. Lee, H. Y. Chang, J. C. Liang, Current status, opportunities and challenges of augmented reality in education, *Computers & education* **62** (2013) 41–49.

[3] M. A. Rau, V. Aleven, N. Rummel, Making connections among multiple graphical representations of fractions: sense-making competencies enhance perceptual fluency, but not vice versa. *Instructional Science* **45** (2017) 331-357.

[4] R. E. Mayer, V. K. Sims, For whom is a picture worth a thousand words? Extensions of a dual-coding theory of multimedia learning. *Journal of educational psychology* **86**(3) (1994) 389.

[5] R. B. Ekstrom, H. H. Harman, *Manual for kit of factor-referenced cognitive tests, 1976*. Educational testing service, 1976.

[6] R. R. Hake, Interactive-engagement versus traditional methods: A six-thousand-student survey of mechanics test data for introductory physics courses, *American journal of Physics* **66**(1) (1998) 64–74. https://doi.org/10.1119/1.18809