Augmented Reality in Electromagnetism: Which representations best support students' understanding?

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Abstract. We have developed an Augmented Reality (AR) learning setup in which students investigate the Lorentz force and the superposition of magnetic fields with virtual representations including field vectors, field lines, a vector tripod, and combinations thereof. In an experimental classroom study with N = 77 students, we found no significant differences in conceptual understanding between the different AR conditions. However, exploratory analysis revealed that conditions employing the vector tripod showed better learning results regarding the conceptual knowledge on Lorentz force. Offering multiple as opposed to single virtual representations did not seem to enhance or hamper the acquisition of conceptual knowledge.

Introduction

Multiple external representations (MER) have proven to foster students' understanding of abstract scientific concepts [1]. While MER can support learners' conceptual understanding during guided experimentation, this combined learning environment also poses high affordances on students. Depending on students' representational competence and knowledge, learning with MER induces substantial cognitive load requiring the integration of spatially and temporally separated information. When students engage in experimentation at the same time, cognitive load further increases, depending on students' prior knowledge and the level of guidance provided during experimentation. In that respect, Augmented Reality (AR) is a promising technology that enables the real-time integration of adaptive virtual representations into the learning environment resulting in spatial and temporal contiguity. As proposed by the Cognitive Theory of Multimedia Learning [2], this may lead to a reduction in cognitive load and better learning results.

Research questions

While extensive research has explored the presentation of (graphical) representations in traditional multimedia learning environments [3], the reasonable selection of AR-based representations in lab work settings requires further investigation.
With our study we contribute to ongoing research on finding meaningful and effective ways to use AR technology in learning physical concepts. The field of application chosen for this study is electromagnetism with special attention to the determination of the direction of the Lorentz force and the superposition of magnetic fields. Our research questions (RQ) are as follows:

RQ1: What virtual representations work best for the acquisition of conceptual knowledge regarding the determination of the direction of the Lorentz force and field superposition?

RQ2: Does the number of displayed virtual representations influence the learning outcome?

Methods and findings

A total of $N = 77$ students (11^{th} grade, 16-17 years old) from the advanced track of a Swiss secondary school participated in an experimental classroom study with a pre-post-test design. In the first part of the study, students watched a learning video on the representation of vector fields followed by a representational competence test. In a second learning video students were introduced to the Lorentz force and possible ways of determining its direction. A conceptual knowledge test on magnetic fields and Lorentz force concluded part one. In the second part, students were randomly divided into seven conditions. They were equipped with AR-smart glasses and conducted individually a series of five experiments on the Lorentz force. Depending on the condition, they were presented with virtual representations including either field vectors, field lines, a vector tripod, or combinations thereof. Written instructions guided the students through the experiments in a predict, observe, explain design. Part two was concluded with questionnaires on cognitive load, system usability, conceptual knowledge, and demographic data.
Regarding the conceptual knowledge on the direction of the Lorentz force, no significant differences between treatment conditions were found. However, an exploratory analysis revealed that groups in which the vector tripod was used (either alone or in conjunction with other virtual representations) showed better understanding than those who were not provided with the virtual tripod. Regarding the conceptual knowledge on superposition of fields, no superior representation was found, and group differences were insignificant. Further, the number of virtual representations offered did not seem to influence the acquisition of conceptual knowledge. System usability was rated as "good" [4], with no significant differences between conditions. No significant differences between groups were also observed for cognitive load, which in general was on the lower end of the scale indicating high availability of resources. This is also reflected in the distribution of representational and conceptual knowledge test scores, which both show ceiling effects.

Conclusion

We developed an AR environment that bears the potential to support conceptual knowledge acquisition while keeping cognitive load low. Regarding RQ1 we have found that there are single representations that support learning better. However, this seems to depend specifically on the learning content. Regarding RQ2 we conclude that the number of displayed representations does not influence the learning outcome. In addition, we received positive feedback from the students. The students enjoyed experimenting with the AR-smart glasses and reported that it made learning physics more interesting.

However, the results of this pilot study should be treated with caution, as the group sizes are rather small. Future research will focus on larger sample sizes and adjusted learning materials in order to avoid ceiling effects, which in turn could make potential group differences more prominent.

References

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