Technology deployment in physics lessons: Understanding optics better with Augmented Reality

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Abstract. The following article presents the results of a seminar on "Augmented Reality in Institutional Education". There, together with STEM trainee teachers, an optics experimentation circle was developed for pupils in the 7th and 8th grade at the Gymnasium for the subject of "Nature & Technology" or "Physics". This includes (real) experiments (lunar phases / eclipses, refraction, refractive error, color mixing), which were enriched with Augmented Reality technology created by the students. By creating a learning scenario with the help of Augmented Reality at school, the real environment continues to be perceived by the students but is supplemented with visualizations of physical model concepts. For example, the refraction of laser light on a water surface in the real experiment was overlaid with a visualization of the physical ray model of light, so that both information can be perceived simultaneously. This offers the students the opportunity to link physical model concepts statically but also in their spatial or temporal change in conjunction with the real experiment and to actively interact with it at the same time. Even without linking to a real object, augmented reality makes it possible to visualize changing processes or three-dimensional movements of virtual objects and to integrate holograms into the real world. We hope that the experiments presented here can demonstrate the benefits of AR extensions to real experiments, so that more applications will find their way into STEM lessons in the future.

1. Introduction
The relatively affordable availability of technical equipment has created many new opportunities for teaching and learning in institutional education in recent years but has also changed the way of teaching. For example, computer rooms in schools have become standard, and with the proliferation of notebooks and tablets, they have also found their way into more and more classes [1][2]. This provides teachers with continuous and direct access to digital educational materials, information from the Internet, and the incorporation of images and video, as well as interactive simulations or even screen experiments and science education apps. This type of teaching can have a particular impact on, and support for, student performance [3]. However, didactic concepts that deal with the added value of these technologies in individual subjects and also deal with the methodical implementation of these new possibilities are often missing for successful use. There is also a shortage of teachers who know the potential of these new technologies and are trained to use them in class [3]. If we talk about Virtual Reality (VR) we mean fully animated, computer-generated environments in which the user can "move" and interact in real time. If a learning scenario with Augmented Reality (AR) is created, the physical reality will continue to be perceived and enriched with digital information (see figure 1).

In the field of institutional education, a number of factors are mentioned which contribute to the improvement of learning in the broadest sense. The use of these technologies enables the visualization of highly complex scientific processes that cannot be visualized in reality [2]. Therefore, we suspect that
with the help of these technologies, we can reduce students' misconceptions in physics and promote highly complex and technically correct modeling [4].

![Milgram's Reality-Virtuality continuum](image)

**Figure 1.** Classification of Mixed Reality according to the degree of immersion [5]

2. AR in physics lessons

Depending on the selected setting, there are fundamental advantages and disadvantages for the use of AR equipment in the classroom, which must be taken into account:

The most important advantages are certainly that you can overlay the real experiments with additional information to make things visible that cannot be perceived otherwise (e.g. optical beam path in the eye, real size ratio of planets to each other), or to give experimentation instructions at the right place.

There are many ways to represent AR content. Probably the most expensive, but unfortunately still poorly developed output medium, are so-called Augmented Reality glasses. Because of their semi-transparent displays the real environment can still be perceived without hindrance. The computer-generated information is then displayed in the right place directly in the field of view. The interaction with the application and the control of the glasses happens mainly with the help of gestures or voice commands. The great advantage of AR glasses is that learners have their hands free and are free to engage in conducting the real life experiment while executing the on-screen instructions or receiving additional physical information [6][7]. Even cooperative work with other learners is possible. Different studies analysed the performance of students in multi-user virtual environments [4][8] and showed positive effects on learning processes, so we think that the collaborative aspects of AR should help to get better learning outcomes [9]. Billinghurst (2012, S. 56) writes: “Multiple Users can experience 3D objects from different viewpoints, interacting with the object and sharing insights, making learning essentially a collaborative experience” [10].

By using Virtual Reality glasses, for example, students are isolated from their environment and so it becomes more difficult for them to communicate with other students or the teaching person. However, as mentioned earlier, AR glasses are currently under development and still far too expensive. Hardware that can be financed by schools and therefore be used without any difficulty, are tablets or smartphones. With the aid of touch inputs, the graphic content of the AR scenario can be intuitively controlled via buttons or sliders. Using tablets to explore the AR learning environments has the advantage of being able to work and learn collaborative together with other pupils and the disadvantage of not having the hands free during the experiments.

In the area of institutional education, teaching research has found a number of factors that improve learning in the widest sense when using VR/AR content [2][3]. For example, Radu (2014) [11] reports that VR and AR technologies have the potential to make learning more effective and motivating and are increasingly accessible for young people and generally easy to use. In addition, AR learning scenarios help to anchor learning contents in the memory for a longer time and to better visualize spatial structures and processes. Wu et al. (2013) [12] also suggest that AR enables ubiquitous, collaborative learning and
presentation of learning content in a 3D view, and can actually make the invisible (e.g., flow of current) visible. Despite these results and the assumption that the use of AR at school has positive effects on learning processes and on learning success, there are so far only very few AR applications with a science technical focus or curriculum reference [3]. The development of useful didactic concepts and the transfer of them into well-functioning AR applications, which can be used by teachers with manageable effort, is therefore very important in the near future. The number of AR learning scenarios would certainly increase if there were intuitive authoring systems that also enable technically less-advanced professionals to create them [3].

Physics teachers are used to motivate physical models in a two-step process based on real experiments, or to make plausible studies of theoretically developed models (and thus abstract ones) using experiments. The big advantage of overlaying real objects / experiments with digital content is that they transfer the physical model concept directly into reality and so they create a visual link between the model and reality (e.g. the magnetic field of a real bar magnet represented in the field line model; ray model of light superimposed on real experiment for refraction). In addition, time-varying processes or three-dimensional movements / processes can be made visible within technical devices. On top to pure visualization, the students' learning process requires the possibility of active interaction and instantaneous (digital) feedback on the action taken [2][9].

3. Creation of the optical experiment circle and material requirements
For STEM teaching students at the University, a seminar on "Augmented Reality in Institutional Education" is offered every semester. Content is the didactical conception of VR/AR-learning scenarios, their implementation, as well as their use in school laboratories or in school practice. In cooperation with a media working group of a partner high school various optic stations were developed, designed and implemented based on the materials already existing in the optics school laboratory.

In the seminar, the students first received a theoretical introduction to the subject of "Latest Media in Institutional Education" and were technically trained to be able to create their own AR applications. For the implementation, the game engine software Unity, coupled with the tracking software Vuforia, is being used. Both programs together allow to develop augmented reality learning scenarios and to blend real objects with digital information. Scripts within Unity are usually implemented in the C# programming language. The advantage of Unity and Vuforia is that it can be applied license-free for non-commercial purposes, which is indispensable for a large-scale dissemination in school.

To complete the learning circle a total of eight tablets is needed. Alternatively, corresponding smartphones with the largest possible display can be used. At the station "Moon phases" there is additionally a virtual reality application, which can be viewed via VR glasses (with integrated smartphone). VR glasses are available as a low-cost Cardboard variant already in the lower double-digit euro range. In order to build up the real experiments, you also need some devices, which are often available in every physics equipment collection in high schools (e.g. optical lenses, water basins).
4. Implementation at school
The aim of the seminar is not only the creation of the stations described below but also their testing with a school class. The four learning scenarios can be run in any order and were set up twice, so that in a "normal size" classroom eight groups of 3 students each can work together. Time should be expected per station with about 15 minutes. The instructions for the individual applications were printed in a "researcher's booklet", which the pupils receive at the beginning of the lesson to record their results, so the teacher can pick up the results in one of the following lessons and discuss it in more detail.

The experimental circle contains the following stations, which can also be used individually in single lessons:

4.1. Station “Human Eye”
An eye model - consisting of lens and screen - is superimposed with the physical beam model of light (see figure 2, left). In addition to depicting the human eye, the AR application visualizes the beam path of candlelight and the physical refractive process when hitting the eye lens. If the focal point of the light rays in the app caused by the lens does not hit the screen (i.e. the retina), this can be seen in the real experiment from a blurred image. The reason for the blurred image is the fact that the focal point of the optical is not located on the retina (the screen), but either in front of or behind it. The existence of a focal point after a converging lens is part of the physical beam model, which in this case can be observed directly in relation to the real experiment. In the real experiment, the blurred image can be corrected by a lens with correct focal length, which was previously determined in the application using a slider. This so-called accommodation is realized in the human eye by a changed shape of the eye lens.

4.2. Station “Refraction”
Light refraction takes place at an optical interface, which is shown by a change in the direction of propagation of the light. If you want to hit an object under water with a rod, you have to aim deeper than you would expect optically. The students can try this out on the real experiment, but without seeing the actual light beam. Therefore, the light path can be digitally correctly overlaid via slide controls to adjust the angle of incidence and the angle of refraction (see figure 2, right). The application allows the determination of the refractive index of the selected liquid.

4.3. Station “Additive Color Mixing”
Embedded in the story of a singer, the effects of additive color mixing are shown in a simulation in which any color can be generated out of three basic colors by addition (see figure 3, left). Another everyday example is a mobile phone display, which can be placed under the microscope to see how the perceived colors are generated.

4.4. Station “Moon phases & lunar/solar eclipse”
To understand the phases of the moon or solar and lunar eclipses, the three-dimensional arrangement of the celestial bodies sun, moon and earth is indispensable. The presentation of three-dimensional processes using two-dimensional images (e.g. the phenomenon of the phases of the moon or solar/lunar eclipses) requires a high level of thinking and imagination on the part of the students. Using augmentation (in this case 3D simulation), the constellation of the celestial bodies can be viewed threedimensionally and from different perspectives. (see figure 3, right). By observing the moving celestial bodies illuminated by the sun, the students recognize the reason for the phases of the moon that can be monitored from the Earth. Because of the implemented shadow formation, it is also possible to observe the formation of a solar eclipse and a lunar eclipse from different perspectives. Eventually, a VR application shows the correct proportions of the celestial bodies with respect to each other.
5. Results & Planned projects

The experience in the seminar at the university has shown that the students were very enthusiastic about creating their own VR/AR apps. Dealing with Unity is initially described as "overwhelming" and "complicated". At the end of the seminar, however, the students are very satisfied, when they usually had a self-created, functioning application. The students welcome the very independent work in the seminar and state that they want to use existing AR applications later in the school.

It is important to integrate the app into a learning context. Didactic considerations should be considered before creating the app, so that the app has a real added value compared to the pure real experiment. It is difficult for the students to correctly assess all aspects at the beginning of the seminar and to distinguish them from pure simulations or the pure scientific real experiment. It is important to test the applications with a school class in order to revise them in an iterative process.

In order to explore the effectiveness in teaching cognitive knowledge content and in particular conceptual knowledge with the help of VR/AR technologies, an augmentation of the real experiments of a complete teaching unit on the subject of "Electricity" is planned. By doing this the extent to which the students are able to model themselves in this area through the use of technology is evaluated, too. It is expected that the formation of misconceptions among learners can be reduced by visualizing certain processes (current flow, etc.) that are otherwise invisible and spatial aspects (3D models that can be interacted with). Furthermore the planned evaluation deals with the usability of different output media (AR glasses, smartphones, tablets, etc.) and to what extent performance can be measured within VR or AR learning scenarios. In doing so concepts of gamification in learning worlds can be useful.

The stations already created are available to teachers free of charge via our website: https://www.physik.uni-wuerzburg.de/pid/physik-didaktik/augmented-reality/

In addition, they will gradually be integrated into the already existing school laboratories of the university. In order to be able to test some of the necessary instruments for the evaluation, a preliminary study will be carried out in school.

6. References

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