The usage of immersive technologies in learning environments

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ABSTRACT

Currently, immersive technologies are enjoying great popularity. This trend is reflected in technological advances and the emergence of new products for the mass market, such as augmented reality glasses. The range of applications for immersive technologies is growing with more efficient and affordable technologies and student adoption. Especially in education, the use will improve existing learning methods.

Immersive application use visual, audio and haptic sensors to fully engage the user in a virtual environment. This impression is reinforced with the help of realistic visualizations and the opportunity for interaction. In particular, Augmented reality is characterized by a high degree of integration between reality and the inserted virtual objects. An augmented interactive simulation for the determination of the specific charge of an electron will be used as an example to demonstrate how such immersion can be created for users. A virtual Helmholtz coil is used to measure and calculate the e/m constant. The voltage at the cathode for generating the electron beam, but also the voltage of the homogeneous magnetic field for deflecting the electron beam, can be variably controlled by haptic user input. Based on these voltages, an immersive virtual electron beam is calculated and visualized.

In this paper, the authors present the conceptual steps of this immersive application and address the challenges associated with designing and developing an augmented and interactive simulation.

Keywords: Education, Augmented Reality, Immersive Technology, Helmholtz coil, Realtime simulation, Virtual experiments, Optics and Photonics

1. INTRODUCTION

A traditional course in a scientific curriculum ranges from theoretical lectures to practical laboratory experiments. With the advance of digitalization, this teaching is being expanded to include further possibilities for imparting and deepening knowledge. New concepts, such as the virtual simulation of experiments, enable the practical application of previously taught theory in virtual space. This effect can be positively enhanced with the utilization of immersive technologies.

In the past, a blended learning concept was developed that combines the advantages of modern digital media with theory and practice.A wide range of digital media is used for this purpose. Particularly emphasized is the usage of images, videos, animations, virtual and augmented reality with the corresponding sensors. The basis is the hands-on experiment to determine the specific charge of an electron e/m with a Helmholtz coil. This laboratory experiment was virtualized in several development steps and supplemented by additional interaction options. The objective of our work is the availability of an experiment from the field of Optics and Photonics using different technologies. A comparison between the technologies with reference to the teaching of educational content permits a valid evaluation. The gain in knowledge can be used for the design of future teaching methods.[1–3]

2. RELATED WORK

This section presents the practical experiment to determine the charge of an electron e/m. Several milestones are highlighted which deal with the realization of an immersive virtual environment for teaching Optics and Photonics. All of these demonstrate the technologies involved and provide insights into the development process.

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2.1 Hands On

With the objective of transferring an experiment from the physics and optics laboratories to a digital respectively virtual environment, the decision was made in favor of the promising experiment for measuring the specific charge of an electron e/m. This is based on the research of J. J. Thomson, who made the first quantitative statements about a cathode ray in 1897. For this purpose, he considered the deflection of the cathode rays in a magnetic field.[4]

Complementing Thomson's experimental setup, Helmholtz coils are used to generate a homogeneous magnetic field. By adjusting the accelerating voltage V_{acc} and the current I in the coil of the magnetic field B, the specific charge can be measured by reading the diameter d of the electron beam. An approximation to the literature value of the specific charge can be determined with the repetition of the measurement process and the subsequent calculation. The figure 1 illustrates such a measurement step.[1]
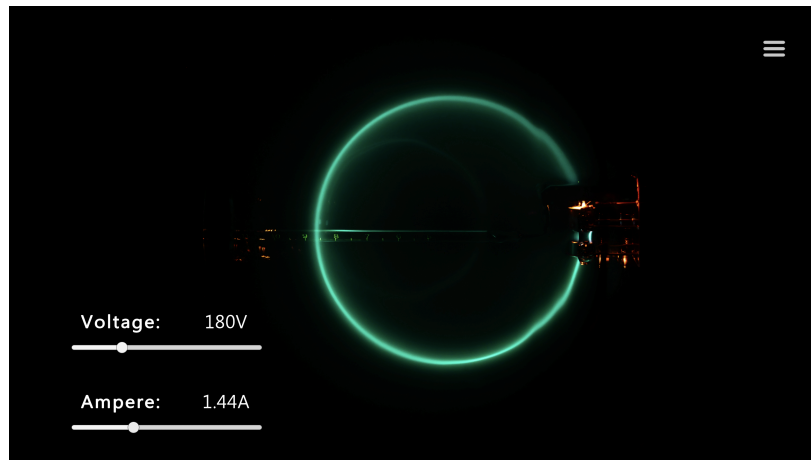

Figure 1. Experiment to determine the specific charge of an electron. Photography by D. Curticapean.

2.2 Virtual Reality Application

A transformation of the presented experiment into a virtual environment is much more complex. This requires a three-dimensional reproduction of all objects involved. In this way, the experiment is carried out realistically in the virtual environment. This includes the Teltron tube and the associated voltage and current generators. A visual impression is given by the following image 2.[3]
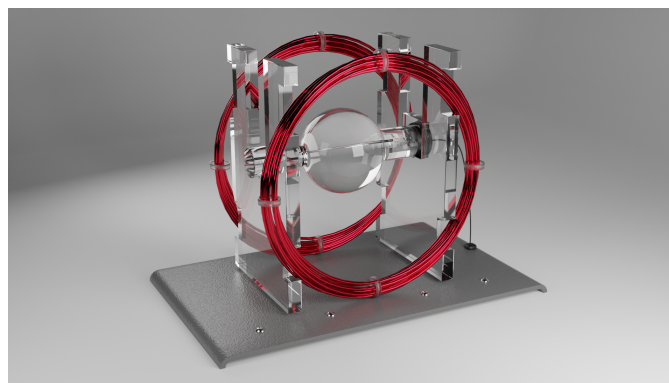

Figure 2. Virtual Teltron tube created with Blender.

3. THEORETICAL BACKGROUND

3.1 Educational Goals

The proposed taxonomy of Bloom[5] is used to define the educational goals. The taxonomy divides the learning objectives into six individual stages, which differ in complexity. In the figure 3 these stages are shown. The cognitive skill level can be consciously controlled as the stage increases.
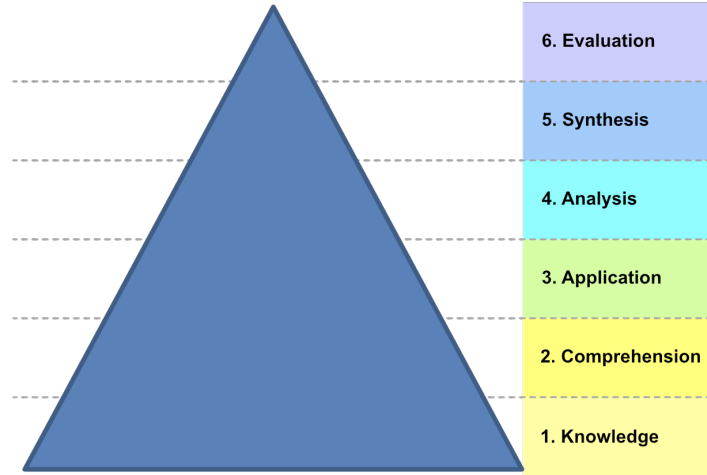

Figure 3. Bloom's taxonomy. Source: B. S. Bloom[5]

The first stage of Bloom's Taxonomy (Knowledge) is the transfer of knowledge to participants. Texts, images, videos, animations, etc. can be used for the transfer.

In the second stage, a review of the acquired knowledge takes place to test whether the participants have understood the learning objectives of the first stage.

The application phase involves the practical implementation of the acquired knowledge. Various options are available for this, such as practical experiments, scenarios or role plays and complex simulations. The focus should be on simulating real problems in order to apply the knowledge and skills learned.

The fourth stage describes the analytical decomposition of elements, relations and order structures based on their context and the subsequent extraction of the ideas, problems and differences.

In synthesis, the participant applies the ability to develop his or her own ideas and concepts based on the content learned.

The last stage of the taxonomy inspires the participant to use the acquired skills and knowledge to analyze and critically evaluate the learned content.

The developed application includes the first four stages of Bloom's taxonomy.

3.2 Determination of e/m

In the virtual space, the physical properties of the experiment must be simulated. This ensures that the measured values in the virtual experiment correspond to reality and that their results are identical. Furthermore, an increased immersion can be achieved by a realistic simulation of the physical laws.[6]

At the beginning of the experiment, a voltage is applied to the electron beam generator, which emits electrons. The emitted electrons are accelerated with the voltage V_{acc} in the direction of the anode to a kinetic energy E_k of

$$E_k = \frac{1}{2}mv^2 = eV_{\mathrm{acc}} \tag{1}$$

and leave through a small gap and enter the glass sphere. In doing so, they have the following velocity v:

$$v = \sqrt{\frac{2eV_{\text{acc}}}{m}} \tag{2}$$

Inside the glass sphere, the electrons collide with argon atoms and ionize them. The kinetic energy is sufficient to put the argon atoms into a higher energy state. When the atoms fall back to their original state, photons are emitted and can be perceived by the human eye. The virtual realization of this visible effect is explained in more detail in the chapter 4.2.

A magnetic field is generated when the Helmholtz coils are switched on. This field acts perpendicular to the direction of velocity of the electrons. The existing Lorentz force F_L steers the electrons with the equation

$$F_L = evB \tag{3}$$

The deflection of the electrons leads to the fact that the electrons are held on a circular path and the applied centripetal force F_C can be described with the radius r:

$$F_C = \frac{mv^2}{r} \tag{4}$$

The ratio of the specific charge can be determined by equating the Lorentz force F_L with the centripetal force F_C. This ratio is composed of the charge of an electron and the mass of an electron, which is given by the following equation

$$\frac{e}{m} = \frac{2V_{\text{acc}}}{B^2 r^2} \tag{5}$$

The specific charge has a value of

$$\frac{e}{m} = 1.75882 \cdot 10^{11} \frac{\text{C}}{\text{kg}}, \tag{6}$$

which corresponds to the literature value.

3.3 Augmented Reality

In the context of this paper, the phrase augmented reality needs to be defined first. Today, there are several definitions. The best known one by Paul Milgram et al. will be discussed here.[7] He theorizes that there are different kinds of realities, which are connected by a continuum. This extends from the real world to the virtual world. The figure 4 shows the corresponding schematic representation of the Reality-Virtuality Continuum.
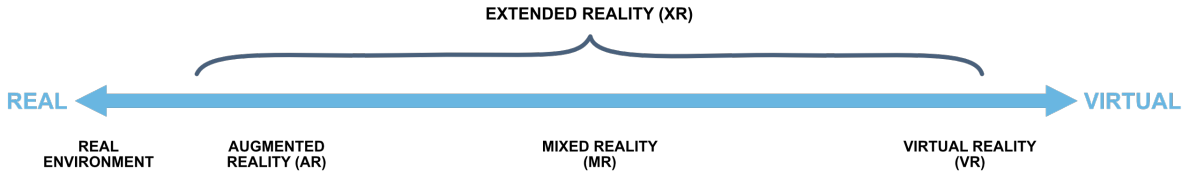

Figure 4. Reality–Virtuality Continuum schematic. Source: A. Benassi[8]

The functionality of augmented reality is limited to linking virtual information with the real world. This type of integration can be realized with the support of various display technologies that overlay and combine information with the user's view.[9]

4. IMMERSIVE APPLICATION

The development of an augmented reality application for mobile devices can be realized by different frameworks. The decision for or against a framework can be made depending on the selected product. In the context of this paper, Nreal AR glasses are used, which are compatible with the most popular operating systems. To make the software available for the numerous operating systems, the Unity Engine is used for development. This engine offers a wide range of functionality and facilitates the use of various libraries such as OpenXR.[10]

4.1 Nreal AR glasses

Augmented reality glasses serve as an interface between the real world and the virtually embedded information. The glasses fulfill two tasks. In the first task, the glasses record information from the real world via an integrated camera. In the second step, the collected data is processed for localization and orientation in the virtual space and forwarded to the corresponding subsystems. Finally, the virtual content is displayed on the glasses display.[11]

The decision to use Nreal AR glasses can be justified by the following points:[12]

- a Full HD resolution per eye

- a FOV of 52 degrees

- a frame rate of 60 Hz

- use the smartphone as the core processing unit

- high compatibility with various input devices

- a provision of software libraries suitable for direct development

- a large community of developers and users offering a fast exchange of information

The developed prototype uses the supplied controller for input, which can be operated with one hand. This is shown in the figure 5 and supports control over 3 degrees of freedom. This includes 360 degree rotation around all three axes. The Nreal SDK library provided is used for software development.[13]

Figure 5. Left: Controller front. Right: Controller back side. Source: Nreal Gitbook[14]

4.2 Immersive Visualization

In the Unity Engine, all objects, whether they are 3D models (meshes) or 2D models (sprites), are managed with so-called materials. These materials describe the visual properties and functions of a body. Technically, the materials are implemented with a shader. Each shader can be considered as a program developed specifically for the graphics card or other acceleration processor. Depending on the performance of the chosen device, the default shaders provided by the Unity engine can be used or custom optimized shaders must be developed. For the prototype, Unity's default shaders will be used. However, it is recommended to replace the shaders with own implementations.[15]

The electron beam described in chapter Theoretical Background is visibly represented in the virtual environment by a two-dimensional line. In order for the electron beam to assume arbitrary curves, the line must be divided into several straight segments. High segmentation further approximates the individual line segments to the ideal curve. A demonstrative approximation is shown in the figure 6.[16]
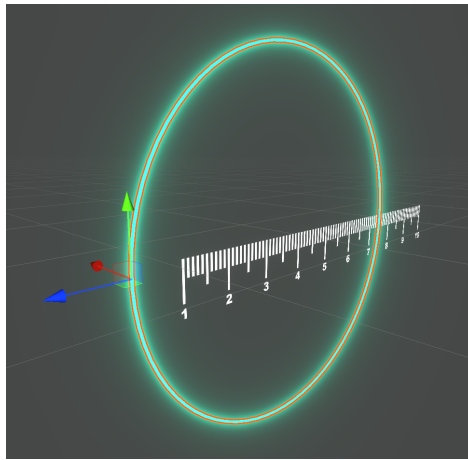

Figure 6. Virtual electron beam generated in Unity Engine.

5. CONCLUSION

The present work has shown that immersive technologies in education can be a valuable tool for teaching applications. Based on the chosen methodology and implementation, it was successfully demonstrated that an experiment from the field of Optics and Photonics could be transferred into the virtual environment.

During the implementation of the prototype, a technical implementation of the electron beam with a line renderer in Unity proved to be quickly visualizable. Unfortunately, the limited two-dimensional representation can only be seen well from certain viewing angles. This problem can be solved by developing a shader. With the introduction of self-developed optimized shaders, a balance between quality and performance can be realized depending on the target device.

A remarkable challenge was the navigation and control in the three-dimensional environment with the immersive technologies. Interaction with the virtual experimental devices relied on use of 3D haptic input sensors. The virtual objects could be displayed and updated synchronously with the movement via a head-mounted display.

The further work will deal with the evaluation of utilized technologies. In the context of teaching, the advantages and disadvantages of each technology are analyzed. This purpose is served by the experiment presented here, which was developed and optimized for each technology. Another important aspect will be collaboration in virtual space. This includes the collaborative editing, research and problem solving of experiments in the field of Optics and Photonics. This is intended to address the aspect of social community currently lacking in immersive technology.

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