Experiencing Physical and Technical Phenomena in Schools Using Virtual Reality Driving Simulator

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Abstract. In the time of globalization and technical advances, companies want to remain competitive on national and international markets. This requires a qualified workforce with a corresponding level of education in the STEM fields. This paper presents a didactic methodology for a virtual reality-based workshop which supplements the school curricula of secondary education institutions. A virtual reality driving simulation application is used in order to enhance the students understanding of different physical and technical phenomena as well as to teach technical skills, such as the ability to program virtual reality applications. We observed that this methodology helps to reduce complexity and aid the understanding of the subject. This is due to the three main contributing factors: Immersion, interaction and engagement. The enthusiasm for the virtual reality systems kept the students motivated not only during the teaching units, but it has also inspired them to pursue the STEM careers.

Keywords: serious games, technology enhanced learning, STEM fields, secondary education, virtual learning environment, driving simulation.

1 Introduction

STEM is an acronym that stands for the fields of study science, technology, engineering and mathematics. These are very important fields with regard to technology and workforce development. Their development directly relates to the national economic competitiveness [1]. Graduate numbers in STEM fields have seen an increase in the past few years, but the demand still has not been met by a large margin. The corporate sector is urgently looking for graduates from the faculties of mathematics, computer science, natural sciences and technology, resulting in excellent opportunities for students with degrees related to the aforementioned subjects. To address the STEM skills shortage, ministries of education take measures and launch campaigns to further promote interest in STEM (for example European Schoolnet [2] or the Federal Ministry of Education and Research in Germany [3]).

Looking at contemporary products, for example from electronic or automotive industries, we witness a rapidly growing complexity. Handling this new complexity requires well-prepared engineers, able to investigate and solve engineering

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problems efficiently and in interdisciplinary teams. Virtual reality (VR) is a technology that can help in dealing with this complexity present both in the industry itself and in the education. With regard to the latter, it can raise the appeal of STEM subjects and bridge the gap between the theoretical knowledge and its practical application to problems in science and industry.

Sherman and Craig [4] define virtual reality as "... a medium composed of interactive computer simulations that sense the participant's position and actions and replace or augment the feedback to one or more senses, giving the feeling of being mentally immersed or present in the simulation". According to Burdea and Coiffet [5], the three most important properties of VR are the so-called "3 Is": Immersion, interaction and imagination. These are realized through multiple input and output devices, enabling the bidirectional information flow between the user and the virtual world. From the technological point of view, we characterize a virtual environment as immersive, if it provides stereoscopic, real size representations of objects, supports user headtracking and offers intuitive interaction.

Due the advantages it offers, VR is often deployed in fields such as medicine [6], automotive [7], aerospace industries [8] and entertainment [9]. One field of application of virtual environments (VEs) is the educational sector [10]. An example of such an interactive, 3-dimensional virtual learning environment is the virtual campus [11]. It opens new types of interactive, visual-spatial learning and therefore enables users to take advantage of its graphical representation of information.

The entertainment industry advances the VR technologies, resulting in hardware available at lower prices and increased customer acceptance. Stereo TVs or head-mounted displays (HMD) for visual output, such as the Oculus Rift, 3D surround sound systems and interaction devices like Kinect or Leap Motion are now affordable for the end user. These are only moderately immersive, but can serve as an alternative to highly immersive yet expensive environments (like CAVEs) for teaching students the fundamentals of virtual reality or employing virtual reality to teach STEM subjects.

Technological advances are leading to familiarization of young people with this new media. From a young age, they are exposed to modern information technologies such as computers, smart devices and game consoles with different interaction devices, as well as stereo output such as 3D TVs and 3D cinemas, making the integration of new media in the classroom very natural for students.

The purpose of deploying VR technologies in education is not only to make lessons more interesting for the students, but also to help their imaginative faculties. VR simulations enable the learners to employ their theoretical knowledge of a certain subject in order to make decisions and observe the results in a safe, controlled environment. Real-time realistic scenarios can be represented virtually, thus saving the costs of lab equipment, while at the same time gaining knowledge and untderstanding of the subject matter. Another clear advantage of using this technology in education are the fun factor and the high level of engagement.

In this paper, we present a methodology, as well as examples of its application, for teaching and increasing interest in STEM subjects among senior grades students in secondary education through familiarization with an immersive virtual reality car driving simulator. In addition to conventional lessons, students can experience physical phenomena and gain technical skills, such as the ability to program VR applications. The following section gives an overview of related works in the area of VR use in education. It is then followed by our methodology. A detailed description of this projects application in a German school is presented in section 4. The paper is concluded with a look on the future work on applications of virtual reality for training and education.

2 Related Works

Not all benefits of virtual learning environments (VLEs) over traditional educational environments have been explored thus far. With regard to the design of effective virtual learning environments it is important to know which features of virtual reality (VR) support cognitive processing [12,13].

In 2006 a study of primary school students examined two different VLEs in comparison to traditional educational methods [14]. The evaluated virtual learning environments included both a complete interactive one as well as a passive one. The VLEs were designed as virtual playgrounds in a Cave Automatic Virtual Environment (CAVE). The passive VLE employed a virtual robot that guided activities. The results indicated that the complete interactive VLE aids primary school students in problem solving, but does not lead to conceptual changes in their thinking. Surprisingly the passive VLE appeared to support the learners recall and reflection abilities, thus hinting at signs of conceptual change in their minds.

Another study describes a VLE [15] for science, physics and chemistry "Virtual Water" at the final year of secondary education and first year of university and indicates that 3D virtual environments may help students with high spatial aptitude to acquire better conceptual understanding of the subject matter. The main advantages according to Trindade et al. are the ability to visualize situations which cannot be seen otherwise and to immerse the students within these situations. Students reported that the stereoscopic view gave them a more tangible grasp of a solid state structures such as that of ice.

There are numerous examples of VLE considering the STEM subjects. One application is the virtual physics laboratory that allows students to control the test environment (gravity, surface friction and atmospheric drag) as well as the physical properties of objects (coefficients of restitution of elastic bodies). The students can both observe physical phenomena at macroscopic and microscopic levels or control the time [16].

An application for mathematics and geometry classes at the latter grades of secondary school and university encourages experimentation with geometric constructions and facilitates learning with the aid of stereoscopy, thus being more effective learning tool than the traditional CAD package [17]. The three dimensional geometric construction tool called "Construct3D", based on the collaborative augmented reality system "Studierstube", uses a stereoscopic head-mounted display and a two-handed 3D interaction tool.

Serious games are being considered as a new method for teaching content and motivate the students for STEM careers. Serious games allow learners to experience situations that are impossible in the real world for reasons such as safety, cost and time. They are also claimed to have a positive impact on the players' development of various skills [18].

Such applications can be implemented in virtual environments on different immersion levels. Miller et al. created and tested a web-based forensic science game among 700 secondary school students [19]. They observed a positive relationship between the role-playing experience and science career motivation as well as significant gain in knowledge of the subject.

A game-based, semi-virtual learning environment called "SMALLab" is presented from Johnson-Glenberg et. al for teaching geology and physics. It relies on multiple modalities: 3D object tracking, real time graphics and surround-sound used to enhance embodied learning [20].

The first cyber classroom lab in Germany was opened in 2009 at Lifecycle Engineering Solution Center (LESC) of the Karlsruhe Institute of Technology in cooperation with the company Visenso [21,22]. During the last six years at Institute for Information Management in Engineering (IMI), we worked on solutions for holistic, interdisciplinary and multilingual education methodologies for the field of engineering by using the benefits of virtual reality and virtual learning environments. In the next section, we present our methodology for experiencing physical and technical phenomena in schools using a VR driving simulator as learning environment.

3 Methodology

The idea behind the project is to enhance the students understanding of different physical and technical phenomena using a driving simulator as testing environment and to utilize appropriate VR technologies to visualize the effects of those phenomena. The aim of this project is the creation of a virtual reality experiment kit for secondary education institutions containing the required hardware and software components along with all necessary teaching materials (for instance exercise sheets and presentations). Using the VR experiment kit, the students acquire and strengthen their interdisciplinary knowledge in the areas of computer science (visual programming), physics (Newtonian mechanics) and technology (control loops). The following goals were defined for this project:

1. to increase the students interest in science and engineering through creative work and hands-on learning
2. to promote the development of skills required for identifying and solving complex, interdisciplinary problems from STEM fields
3. to create situations that reinforce the connection between thinking, action and intuition

4. to stimulate individual and self-determined learning
5. to strengthen the students imaginative faculties using modern media
6. to create a sustainable inner drive for further education in engineering and science

The learning approach is similar to serious games but supported by virtual reality. The focus lies on STEM topics with lessons on VR technologies, basics of computer graphics programing and 3D content authoring. 3D immersive representations aid the students in absorbing new information with greater ease, as they can perceive it in an adequate manner using multiple senses, thus seeing and hearing simultaneously.

The didactic method used is the so-called sandwich strategy. The teaching unit consists of 90 minutes and is divided in multiple activities with the maximum duration of 20 minutes each. These activities can consist of theoretical explanations in front of the class, presentations, discussions, individual programming sessions and testing of the results with the VR setup. This strategy helps in keeping the students focused and motivated as well as in aiding their understanding of the subject matter.

The labs are designed in a modular manner, so they can be easily reconfigured for students of varying grades and educational backgrounds. The teachers can select the topics in an arbitrary manner depending on their schools curriculum. Each topic comes with a standalone programming exercise. This results in a decrease of programming complexity and fosters the concentration of the students on the problem-setting.

The proposed solution is designed to support conventional science lessons in form of extracurricular activities (further referred to as workshops). Another important aspect of the proposed solution is the possibility of collaborative work, which supports interdisciplinary communication and problem solving. The workshop can be divided in the following four parts: introduction to virtual reality and the authoring tool, teaching units, demonstrations of VR and evaluation.

3.1 Introduction

The first teaching unit starts with an introduction to the project, followed by a presentation about virtual reality, its definition and characteristics. At this point, it is important to differentiate between the perception of virtual reality from the point of view of entertainment media, such as science fiction literature and cinema, and the currently available hardware and software.

The next step is to present the virtual reality development environment that will be used for the exercises. The employed software tool has been chosen for its visual programing paradigm that allows to easily implement behaviours in the virtual world. This decreases the programming difficulty level that the students have to achieve and eliminates the need to learn a programming language.

3.2 Exercises

Each exercise has a typical structure following the sandwich strategy described above. First the topic is introduced, describing the problem with its definition, formula and real life examples. The subject should be selected to be something that the students are already familiar with or have already studied as a part of their curriculum. The suggested approach is to organize a group discussion and ask the students to explain the presented problem in their own terms, meanwhile writing down all suggestions on the black board. The main part is a tutored exercise where each student works on the same assignment. The students are asked to investigate and learn independently the influence of system variables on the exercise outcome.

For example, an exercise from the field of Newtonian mechanics could be conducted by simulating the free parabolic trajectory of a car launched from a ramp (see Fig. 1). The students could be tasked with the creation of a visual script that would allow to alter the cars power output as well as the angle at which it is launched. The students would then conduct the experiment several times, noting down the variation among distances the car traveled depending on the figures entered for the two aforementioned parameters. The recorded distances, as well as the entry parameters, can then be presented in a tabular form and verified with regard to their correspondence to established physical models.

3.3 Experiencing Virtual Reality

The solutions from the exercises are presented at the end of the lesson. The best solution can be deployed on the VR setup to experience it in an immersive environment. The chance to test the results in the driving simulator should keep the students motivated while they are completing the tasks. The first contact with immersive virtual reality environments should be as early as possible, preferably during the first unit. It is important to demonstrate different VR hardware, software and applications at the beginning of the workshop, combining both, theory and practice.

3.4 Evaluation

Both, the success of the workshop and the students' performance can be evaluated by conducting discussions with the participants or through the use of questionnaires. There is a possibility to measure the improvement in knowledge acquisition with written tests, conducted at the beginning and at the end of the workshop.

4 Application

The pilot project Driving Simulator in Virtual Reality - DRIVE was a workshop in schools that expanded their traditional laboratory exercises in order to

Fig. 1. Exercise on the free jump and testing it on the driving simulator

give the students the opportunity to experience physical phenomena in VLEs. The target group included public school students from Baden-Württemberg, Germany, grades nine through twelve. The entirety of the workshop lasted one term. The project covered three topics: control loops, energy and mechanics. A total of 18 teaching units took place, with a duration of 90 minutes each.

4.1 Equipment

The driving simulator was introduced in the classroom as a low cost VR setup, serving as a basis for virtual reality exercises. Originally the driving simulator was developed by students of the Karlsruhe Institute of Technology during a practical course on virtual reality [23]. The hardware used for the stereo visual output consists of powerwall equipped with headtracking. The students at the university built a seat-box with a real car seat and used the gaming controller Logitech G25 as car interface (steering wheel, pedals and gear lever). The software solution contains a 3D model of the car, a racing track, the environment, weather conditions and sound. The most important part of the package was the driving simulation and the physics (e.g. collision detection).

The Einstein Gymnasium has a well-equipped computer lab with internet-connected laptops available to each student (see Fig. 2). These are a necessary prerequisite for any type of programming workshop or IT driven lesson. The virtual reality system had been added to the classroom like the one constructed by the students in the virtual reality practical course, but instead of powerwall HMDs were used. This setup is quite immersive but still low-cost and thus affordable for a school that would want to adopt the project's methodology. The total hardware cost was approximately €2000, which included a computer, an HMDs, a car seat and a Logitech wheel.

The students had the opportunity to visit the labs at LESC at IMI. The center was established in 2007 as a central platform for the institute's research results, the interdisciplinary exchange of knowledge at KIT and the transfer of technology into practice. The laboratories are equipped with state-of-the-art VR hardware and software. The first lab has a high-end virtual reality environment with a distributed stereoscopic visualization in a three-sided CAVE setup,

Fig. 2. Students working on the programming task

which allows the user to dive into virtual worlds. The second lab consists of a mobile powerwall and contains haptic devices. Both labs have an ART tracking system for headtracking and interaction. Moreover, 3D monitors, HMDs, depth cameras, data gloves and smart devices allow to experiment with low-cost VR environments. A computer pool with powerful workstations is used for 3D content authoring, application development and teaching courses.

4.2 Software

For the DRIVE project the VR authoring tool 3DVIA Virtools from Dassault Systèmes was used. It features a graphical programming interface with functional blocks connected by lines that either represent the workflow or the parameter references. The graphical programing paradigm allows a fast prototyping of logic in a virtual world, without having prerequisites like programming skills or advanced knowledge of computer science. The software comes with a good documentation. During the work with 3DVIA Virtools some drawbacks were noticed. The tool lacks a larger community, this makes it difficult to solve problems through the use of forums or mailing lists. A further problem for the suites future adoption in schools are the high incurred costs for licenses and the end of support in 2014.

4.3 Exercises

The exercises are structured around three main topics. Energy is the first topic where we address the energy management in a car. The second topic introduces control loops, the third some basic Newtonian mechanics. All topics have been chosen to fit the theme of car dynamics simulation. As the students proceed, the exercise grows in complexity providing fewer hints than the previous one. At the same time the amount of basic functions grows with each following exercise as more advanced features are implemented.

Energy. The first exercise addresses the topic fuel consumption. The task is to program in an appropriate consumption rate that varies depending on the use of the throttle. The gas tank and the fuel gauge are modeled at the same time. The students learn the relations between the different variables. For instance they have to model the fuel consumption using a Bèzier curve.

The second exercise implements a visual feedback for the wind resistance. Again a Bèzier curve is used to map two parameters. The last exercise consists of recovering energy from the car brakes when slowing down. A booster meter fills up every time the car slows down using the brakes. Once the meter is filled, a key press releases additional torque on the wheels.

Control Loops. The first exercise in the control loops unit features an automatic car light control. The intensity of the car lights is adjusted, depending on the output of two sensors: the car light sensor and the daylight sensor. The second exercise is an automatic windshield wiper. The third is an extension of the first with an indicator for the lights state. Here, we introduced the concept of RGB colors (see Fig. 3). The final exercise in this unit is centered around the automatic control of the cars sunroof. The automatization works through the use of a rain sensor. Furthermore, the students had an opportunity to implement the ability to control the sunroof directly through a push of a button on the Logitech wheel.

Newtonian mechanics. The Newtonian mechanics unit is the largest of the three and consists of six exercises. It starts with a free jump simulation where a launched car has to cross a trench. The width of the trench is constant, only the height between the two sides of the trench and the engine torque can be adjusted. The speed at the beginning of the jump is recorded. This allows the students to validate the theoretical height for a successful jump.

The second exercise puts the free jump in another setup. Now the car is launched from a ramp, which effectively changes the starting angle of the jump. This exercise also includes loading a 3D model in the scene.

The third exercise focuses on friction, demonstrating the driving behaviour depending on the adjustable friction coefficient of the road. An advanced feature

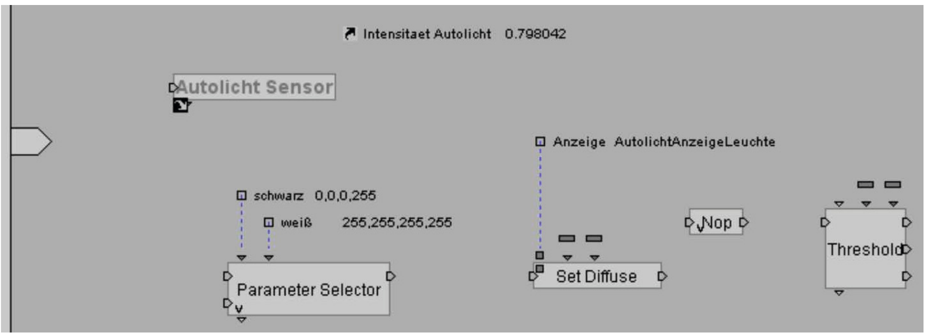

Fig. 3. 3DVIA Virtools script - programming task

of this exercise is the use of a quad generating function that represents the road surface depending on the friction coefficient.

The fourth exercise builds on the previous one. Now the braking distance has to be computed and displayed depending on the friction coefficient and the speed just before pushing the brake.

The fifth exercise allows to tilt the track in a curve sideways at an angle. The goal of this exercise is to discuss the centrifugal and centripetal forces acting on the car and how this changes when tilting the track in a curve sideways at an angle. The last exercise exemplifies the law of conservation of momentum. The students have to observe and discuss the behaviour of the car when crashing into a static object of a mass lesser, equal or greater than that of the car. The second part consists of crashing into a moving object.

5 Conclusion and Future Works

The enthusiasm for virtual reality system kept the students engaged even through some of the less exciting parts of the exercises, thus suggesting that VR approaches result in superior motivation, retention and intellectual stimulation, as well as a better conceptual understanding of the subject matter.

The methodology has been validated by acquiring feedback from the students. The driving simulator was recognized as a valid and beneficial tool for imparting a better understanding of physical concepts and phenomena. The students were able to discern connections between physical principles and their application in vehicles. Furthermore, by performing the tasks offered by our approach, they were able to better understand the interplay between physics, computer science and technology. Various aspects of the pilot project were of particular interest to the participants of the workshop, resulting in diverse suggestions and heterogeneous feedback. Eleven of the twelve surveyed students would recommend the workshop to a friend. During this project, the students also made minor, voluntarily expansions to the driving simulations program code.

The teachers also considered the project to be a success and not only intended to organize the workshop again at future point in time, but also decided to use the topics from the pilot in the schools regular STEM lessons. Some of the students from the pilot are now studying machine engineering and computer science at the university level.

For future research, we suggest involving more homogeneous groups with regard to the participants age when conducting the workshop. Unfortunately our findings will be non-generalizable without a method for evaluating the impact of virtual reality on learning. This is a good opportunity for further investigation.

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References

1. National Research Council: Rising above the gathering storm: Energizing and employing america for a brighter economic future (2007)
2. European Schoolnet (2014), `http://www.eun.org/` (accessed February 21, 2014)
3. Bildungsministerium für Bildung und Forschung: Perspektive MINT-Berufe: Förderung von Technik und Naturwissenschaft (2014), `http://www.bmbf.de/de/mint-foerderung.php` (accessed February 21, 2014)
4. Sherman, W.R., Craig, A.B.: Understanding virtual reality: Interface, application, and design. Elsevier (2002)
5. Burdea, G., Coiffet, P.: Virtual reality technology. Presence: Teleoperators and Virtual Environments 12(6), 663–664 (2003)
6. Riener, R., Harders, M.: Introduction to virtual reality in medicine. In: Virtual Reality in Medicine, pp. 1–12. Springer, Heidelberg (2012)
7. Jiang, M.: Virtual reality boosting automotive development. In: Ma, D., Fan, X., Gausemeier, J., Grafe, M. (eds.) Virtual Reality and Augmented Reality in Industry, pp. 171–180. Springer, Heidelberg (2011)
8. Stone, R., Panfilov, P., Shukshunov, V.: Evolution of aerospace simulation: From immersive virtual reality to serious games. In: 2011 5th International Conference on Recent Advances in Space Technologies (RAST), pp. 655–662 (June 2011)
9. Hsu, K.S., et al.: Application of a virtual reality entertainment system with human-machine haptic sensor device. Journal of Applied Sciences 11, 2145–2153 (2011)
10. Sampaio, A., Henriques, P., Martins, O.: Virtual reality technology used in civil engineering education. Open Virtual Reality Journal 2, 18–25 (2010)
11. Zhao, H., Sun, B., Wu, H., Hu, X.: Study on building a 3d interactive virtual learning environment based on opensim platform. In: 2010 International Conference on Audio Language and Image Processing (ICALIP), pp. 1407–1411 (November 2010)
12. Bowman, D.A., Sowndararajan, A., Ragan, E.D., Kopper, R.: Higher levels of immersion improve procedure memorization performance. In: Proceedings of the 15th Joint Virtual Reality Eurographics Conference on Virtual Environments, pp. 121–128. Eurographics Association (2009)
13. Häfner, P., Vinke, C., Häfner, V., Ovtcharova, J., Schotte, W.: The impact of motion in virtual environments on memorization performance. In: 2013 IEEE International Conference on Computational Intelligence and Virtual Environments for Measurement Systems and Applications (CIVEMSA), pp. 104–109 (July 2013)
14. Roussou, M., Oliver, M., Slater, M.: The virtual playground: an educational virtual reality environment for evaluating interactivity and conceptual learning. Virtual Reality 10(3-4), 227–240 (2006)
15. Trindade, J., Fiolhais, C., Almeida, L.: Science learning in virtual environments: a descriptive study. British Journal of Educational Technology 33(4), 471–488 (2002)
16. Bowen Loftin, R., Engleberg, M., Benedetti, R.: Applying virtual reality in education: A prototypical virtual physics laboratory. In: Proceedings of the IEEE 1993 Symposium on Research Frontiers in Virtual Reality, pp. 67–74 (October 1993)

17. Kaufmann, H., Schmalstieg, D., Wagner, M.: Construct3d: A virtual reality application for mathematics and geometry education. Education and Information Technologies 5(4), 263–276 (2000)
18. Susi, T., Johannesson, M., Backlund, P.: Serious games: An overview (2007)
19. Miller, L.M., Chang, C.I., Wang, S., Beier, M.E., Klisch, Y.: Learning and motivational impacts of a multimedia science game. Computers and Education 57(1), 1425–1433 (2011)
20. Johnson-Glenberg, M., Birchfield, D., Savvides, P., Megowan-Romanowicz, C.: Semi-virtual embodied learning-real world stem assessment. In: Annetta, L., Bronack, S. (eds.) Serious Educational Game Assessment, pp. 241–257. Sense Publishers (2011)
21. Zimmermann, M., Wierse, A.: From immersive engineering to selling and teaching. In: Virtual Reality and Augmented Reality in Industry, pp. 191–198. Springer (2011)
22. Ovtcharova, J.: Prof. Dr. Dr.–Ing. Jivka Ovtcharova eröffnet zusammen mit VISENSO das erste C3-Lab (2014), `http://www.imi.kit.edu/1521.php` (accessed: February 21, 2014)
23. Häfner, P., Häfner, V., Ovtcharova, J.: Teaching methodology for virtual reality practical course in engineering education. Procedia Computer Science 25, 251–260 (2013)