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Teaching Methodology for Virtual Reality Practical Course in Engineering Education

Polina Häfner*, Victor Häfner, Jivka Ovtcharova

Karlsruhe Institute of Technology, Zirkel 2, Karlsruhe 76185, Germany

Abstract

Virtual reality is widely used in the industry and is becoming more and more affordable for end users. At the same time higher education students want to be well-prepared for their professional life and expect more courses with practical application of theoretical knowledge acquired during their studies. Moreover, they benefit greatly when having the possibility to improve their soft skills.

This paper presents the teaching methodology for a practical course in virtual reality for graduate and undergraduate students. The course design focuses on learning about virtual reality by simulating interdisciplinary industrial projects and it aims at developing skills such as methodical approach to practical engineering problems, teamwork, working in interdisciplinary groups and time management. In addition the paper discusses the importance of the course design, task specification and work group composition for a successful realization of the course and refers to some project examples from the past three years.

Keywords: virtual reality; higher education; teaching methodology; practical course; interdisciplinary student project;

1. Introduction

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

* Corresponding author. Tel.: +49-721-608-44157; fax: +49-721-608-43984.
E-mail address: polina.haefner@kit.edu.

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and solve engineering problems efficiently and in interdisciplinary teams. Furthermore, working in a team requires strong soft skills. On the other hand, a new generation of engineering students is beginning their higher education and academic institutes have to introduce them to appropriate technologies for their successful transformation into the industries [1]. Engineering courses must be developed in line with the real and constantly evolving requirements of the industry [2]. One important discipline is virtual engineering and its methods such as virtual reality (VR). Today the numbers of VR courses worldwide has risen, but most of the courses are theoretical and are deriving from computer graphic courses and cannot provide all of the required practical and soft skills.

Virtual reality is largely used in medicine [3], automotive [4-5], and aerospace industries [6], education [7] and entertainment [8]. Our understanding of VR is based on the human-centered definition of Sherman and Craig [9], who describe it 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". This definition clearly emphasizes the three most important properties of VR, the so-called "3 I's" according to Burdea and Coiffet [10]: immersion, interaction and imagination. VR is realized through multiple input and output devices, which enable the bidirectional information flow between the user and the virtual world. We characterize a virtual environment as immersive from a technological point of view if it provides stereoscopic presentations of objects in real size as well as head-tracking of the user. The entertainment industry pushes the VR technology, so that the hardware becomes cheaper and customer acceptance increases. Stereo TVs or head mounted displays (HMD) like Oculus Rift for visual output, 3D surround sound systems and interaction devices like Kinect, Leap Motion or MYO armband are now affordable for the end user. These are moderately immersive but can serve as an alternative to highly immersive yet expensive environments (like CAVEs) to teach students in the fundamentals of virtual reality.

To meet the challenge of industry oriented VR courses, we designed a practical course for university students with a focus on learning virtual reality by simulating an interdisciplinary industrial project. In each semester fifteen students of different degree programs (such as mechanical engineering, mechatronics, computer sciences, physics and engineering management) have the possibility to attend this course and form interdisciplinary and often international groups. The goal of the practical course is to help students acquire knowledge of virtual reality hardware, software and applications through practical tasks in form of projects. They get the chance to design a solution to a complex task in a team. They must take into account the interfaces between the sub-tasks and then merge the sub-tasks into a complete product. The targeted skills are a methodical approach to practical engineering problems, teamwork, working in interdisciplinary groups and time management.

In this paper a teaching methodology for a VR practical course is described in detail. The first two chapters present similar practical courses, the infrastructure used and the boundary conditions. The realized projects show the results achieved by the students and as well as examples for task definition and assignment. To conclude the authors present student's evaluation of the course and discuss the issues encountered during the realization of the course.

2. Related works

Burdea [11] was one of the first authors concerned about the problems of teaching virtual reality. He described some issues like the need for experienced lecturers and dedicated laboratories and the lack of supporting textbooks and lectures for VR courses. He focuses on a broad usage of VR technology and the need for such courses due to a growing job market for VR specialists. Burdea's informal worldwide survey showed that only 148 (3%) universities in 2003 [11] and 273 in 2008 [12] offered virtual reality courses. Since then the number of VR courses increased and most of them take place in form of lectures and exercises. The still relatively small amount of VR practical courses offered in academia use different teaching methodologies, various hardware and software platforms. Often the courses are offered only to computer science students as a complement to a computer graphics course [13-15].

An introductory undergraduate VR course is presented by Stansfield [14]. The course has both a traditional lecture-based and a hands-on, experiential components and provides an opportunity for additional capstone experiences. In addition the students' communication skills are enhanced by writing and presenting research papers. Miyata et al [16] created an educational framework for developing VR applications. The graduate students work in interdisciplinary groups, creating VR applications as a part of a competition. The competition motivates the students to learn during the project development and to improve their collaboration skills. Each project has different content and is focused on creativity. It is important that the ideas are coming from the students. Most of the applications are related to entertainment topics such as games.

Another interdisciplinary course with technical (computer science) and non-technical (art) students is described by Zimmerman and Eber [17]. The course comprises traditional lectures on both artistic and programming topics, demonstrations, research topics presentations and group labs. Each group creates an artistic virtual environment over the course using HMDs and software WorldUp.

Fallast and Oberschmid refer to an interdisciplinary student project in the field of the product innovation process[18]. The challenge is the remote collaboration between interdisciplinary, intercultural and international student teams working on tasks given by an industrial sponsor.

The virtual reality practical course in this paper is designed for students from different engineering fields like mechanical engineering, mechatronics, electrical engineering, computer sciences, physics and engineering management. It is offered in a curriculum together with lectures in virtual engineering, product lifecycle management, information engineering and some practical CAD courses. Our course combines various teaching methods like lectures, demonstrations and hands-on techniques in form of labs.

3. Infrastructure

The course is hosted in the laboratories of the Lifecycle Engineering Solution Center (LESC) in the Institute of Information Management in Engineering (IMI) at the Karlsruhe Institute of Technology (KIT). 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. At the LESC there are four laboratories equipped with state of the art VR hardware and software. In the VR lab a high-end virtual reality environment with a distributed stereoscopic visualization in a three-sided CAVE setup allows to dive into virtual worlds, see Fig. 1 (a). The CAVE has a size of 4,93 m x 1,95 m x and 2,6 m and uses circular polarization for the stereoscopic effect with 12 million pixel resolution. The mixed reality lab consists of a mobile powerwall (2 m x 1,5 m) and two haptic devices, see Fig. 3. Both labs have an ART tracking system for head-tracking and a flystick2 for interaction.

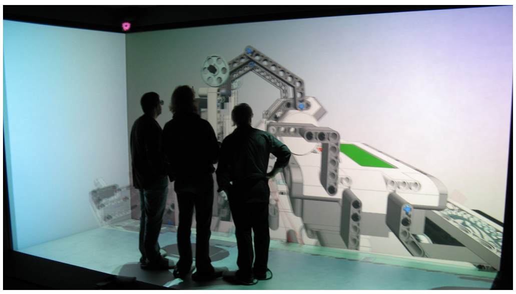

Fig. 1. (a) Three-sided projection in the virtual reality lab in LESC; (b) Energy Experience Lab in LESC

The third lab called "Energy Experience" has 3D monitors, HMDs, depth cameras, data gloves and smart devices giving the possibility to experiment with low-cost VR environments, see Fig. 1 (b). A computer pool with powerful workstations is used for 3D content authoring, application development and teaching courses.

The software platform used for the VR practical course at the beginning of 2010 was 3DVIA Virtools from Dassault Systèmes. The advantages of this software were the present documentation and the provided visual programming paradigm allowing students to develop applications with greater ease. During the work with 3DVIA Virtools some drawbacks were noticed: There is no large community centered around it, the "visual code" becomes too complex with each semester and the code is hard to understand and sustain. Complex manual configuration of underlying VR hardware was needed and high costs for licenses incurred.

To support our high-end-visualization center LESC, we developed our own virtual reality engine "PolyVR", which is also used for teaching purposes. PolyVR is based on open-source libraries like OpenSG [19] and OpenGL and uses the C++ programming language. OpenSG is the backbone of our solution and features a scene graph management with the focus on clustering and threading. The modular architecture of the VR framework facilitates the extension with new features, while the engine grows with every new research project. The lack of good documentation is compensated by live support.

Other software tools used during the practical course are the administration platform ILIAS [20], GIT for version control as well as various ticket and project management systems.

4. Teaching methodology

All graduate and undergraduate students from KIT studying mechanical engineering, mechatronics, electrical engineering, computer science, physics or engineering management can take part in the course. The only restriction is the completion of their fifth semester. Usually 15 places are offered per semester. The number of students from each discipline can vary. The total amount of time and effort is 120 hours during the semester (15 weeks), which corresponds to 4 credits. Each student is interviewed briefly to establish the level of their knowledge, competences, skills, interests and expectations. This information makes the task specification easier, ensuring that the interests of students are also taken into account. This leads to higher motivation, better project results and acquirement of targeted knowledge and skills.

4.1. Course design

The practical course involves four overlapping phases and combines different teaching methods, see Table 1. In the first three weeks the students are introduced to virtual reality in form of lectures and demonstrations, granting all students have the same theoretical background. Short presentations on topics "Definition and application of VR", "Hardware for VR" and "Software techniques and solutions for VR" are alternated with demonstrations in the labs. In this way students gain better understanding of the VR concepts and stay focused during the lectures.

During the next phase, lab exercises take place for task-specific software. Usually introductions to the modeling tool Blender, CAD software like CATIA and VR solutions like 3DVIA Virtools and PolyVR are given in form of labs.

The third and longest phase (about 9 weeks) contains project work in small groups on a given task. The phase starts with the task assignment and group composition in the first two weeks. The task specification is carefully designed by the course supervisors to meet the goals of the practical course and also the interests of the students. Each group has a further optional task. The group's members decide how to distribute the subtask within the team.

Table 1. Common time schedule of the practical course by phases.

Phase / Week	1st	2nd	3rd	4th	5 – 14th	15th
Introduction	Lectures and demonstrations	Lectures and demonstrations	Lectures			
Labs		3D modeling	VR software	VR software		
Project work		Tasks assignment		Project plan presentation	Project work	
Evaluation					Soft skills evaluation	Final evaluation

To simulate an industrial project work environment there is a project manager, usually an engineering management student, and interdisciplinary groups, which usually consist of students from mechanical engineering, computer science and engineering management. The hierarchy and communication between the course members can be seen on Fig. 2 (a). The project leader looks after the project planning, organization, budget and progress, team coordination, conflict management and communication with the course supervisors. In some projects there is also a technical leader position.

After the task specification, the students have two weeks for research and planning. After that period they present the time plan with milestones, the budget preparation and the solution approaches for all tasks. Very important during the planning phase is the early identification of the interfaces between the groups and sub-tasks. All practical course members usually meet every two weeks to discuss the progress of the project and occurred problems. During this phase the course members are free to choose project supporting software tools like project management tools, communication tools or ticket systems.

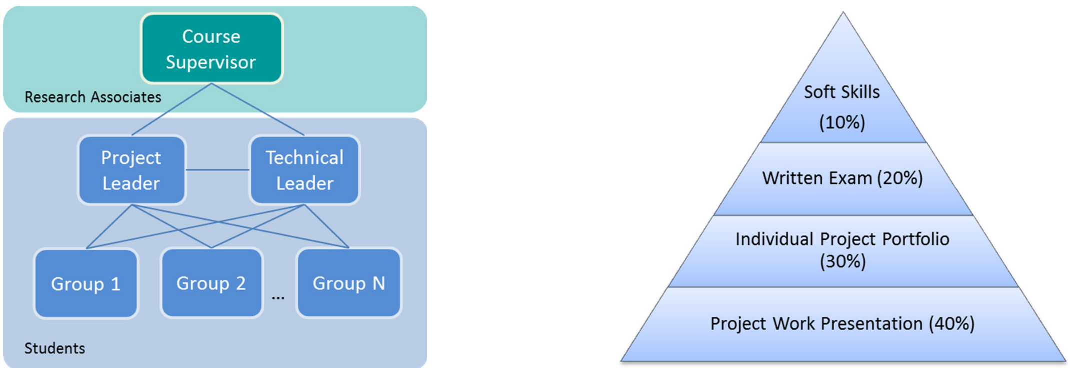

Fig. 2. (a) Hierarchy and communication paths for all course members; (b) Evaluation components

The VR practical course encompasses a complex evaluation starting during the third phase with a continuous assessment of social skills, see Fig. 2 (b). One of the most important components is the presentation of the project work and results. The students can practice their communication skills discussing their work in a given time frame. The next component is so-called individual project portfolio. This document has two purposes. First the students learn to write project documentation, which again is used as reference for the students in the following semesters. This is due to the fact that the projects are sustainable and realized over multiple semesters. The project portfolios describe personal motivation behind the project and reflect on individual learning progress. The project manager writes his portfolio in the form of a project report, combining information about all project results. Short knowledge retrieval in written form is the last evaluation component. The students have to explain two terms from the content of the lectures and demonstrations at the beginning of the course.

5. Projects

5.1. Immersive driving simulator (DRIVE)

The first prototype realized during several semesters was a driving simulator in mixed reality, see Fig. 3(a). The hardware for visual output is a powerwall equipped with ART tracking system for head tracking, and a computer cluster. The students build a seat-box with a real car seat and used the gaming controller Logitech G25 as car interface (steering wheel, pedals and gear). The software solution was realized with 3DVIA Virtools. The students had to implement a virtual world, which contained a 3D model of the car, a track, the environment, weather conditions and sound. The most important part was the driving simulation and physics (e.g. collision detection). For this task the physics pack of 3DVIA Virtools was used, ensuring that a change in weather conditions resulted in a respective change of friction parameters and textures. The students learned to implement a virtual camera, head tracking and set up the visual output using computer cluster.

Over the semesters each element was improved, for example with a generation algorithm for the track to allow its customization before starting the simulation. The environment got more complex over time and manual gears were implemented in the driving simulation.

Fig. 3. (a) First prototype of DRIVE project in MR lab; (b) Second prototype of DRIVE project using real car as input device

The second prototype of the driving simulator started with a real car (Smart Fortwo) donated by the Daimler AG company, see Fig. 3 (b). The challenge was to integrate the car into the simulation. This was achieved within two semesters using different approaches. The first implemented approach was to embed the Logitech sensor in the car and use the existing software interface. During the next semester the students used reverse engineering methods, in order to utilize the CAN-bus system of the car. Now it is possible to send signals from the car to the computer and back. This allows accessing all of the cockpit instruments and common interfaces. Due to the disadvantages of 3DVIA Virtools described above, a new software solution was developed using the virtual reality framework PolyVR in combination with Matlab/Simulink. Tasks such as simulation visualization and creation of a virtual environment had to be performed again. Sound effects were implemented using a 5.1-channel sound system integrated in the car. Using the car as an input device for VR caused some problems like the need of a new solution for head tracking and the students developed head tracking based on the Kinect depth camera. In the coming semesters the immersive driving simulator will be improved further.

5.2. Immersive car cockpit configurator (IC³)

Another application developed by the students during the virtual reality practical course was an immersive car cockpit configurator (see Fig. 4). The configurator was deployed in the virtual reality lab using the three-sided stereo projection system. As an input interface the optical tracking system ART for head tracking and a flystick2 device for interaction was used. Two groups of machine engineering and engineering management students had to identify the customer's preferences using questionnaires and then create variant cockpit elements using CAD software. The purpose of the configurator was to help measuring customer preferences in an early design phase of the product development. Six different elements and four different materials can be changed.

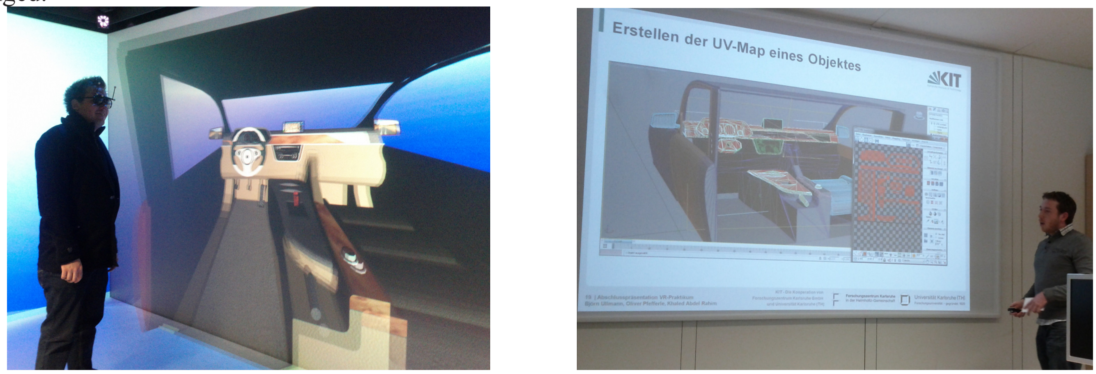

Fig. 4. (a) Immersive car cockpit configurator (IC³) project; (b) Student presentation on IC³ project

A mixed group with computer science and engineering management students had to import the 3d models and implement the configurator and the interaction in the virtual environment. After the implementation a study was conducted and the results were statistically evaluated. This is a good project example of how to compose the groups and tasks so that students from machine engineering, informatics and engineering management can work successfully together.

5.3. Energy experience VR demonstrator(EEVR)

The research in energy and resource efficiency gets more and more popular. We created a virtual reality application simulating user behavior in a public building (e.g. office) and visualize the collected data of the consumed energy. In this project a mobile virtual and a real demonstrator was combined using smart devices (smartphones or tablets) for interaction with the physical sensors and actuators (see Fig. 5). As a virtual demonstrator a 3D passive TV set is used for the visual output. The user behavior and the animations were implemented in PolyVR using a very detailed three dimensional Blender model of our institute's building. The physical part of the demonstrator is provided with different sensors (temperature, humidity, CO_2) and actuators (for opening and closing door or window, switching on and off lights or the computer). Both parts are controlled simultaneously with a tablet. Different 3D and 4D visualization paradigms, known as immersive visual data mining, for displaying the sensor data in the virtual environment were implemented.

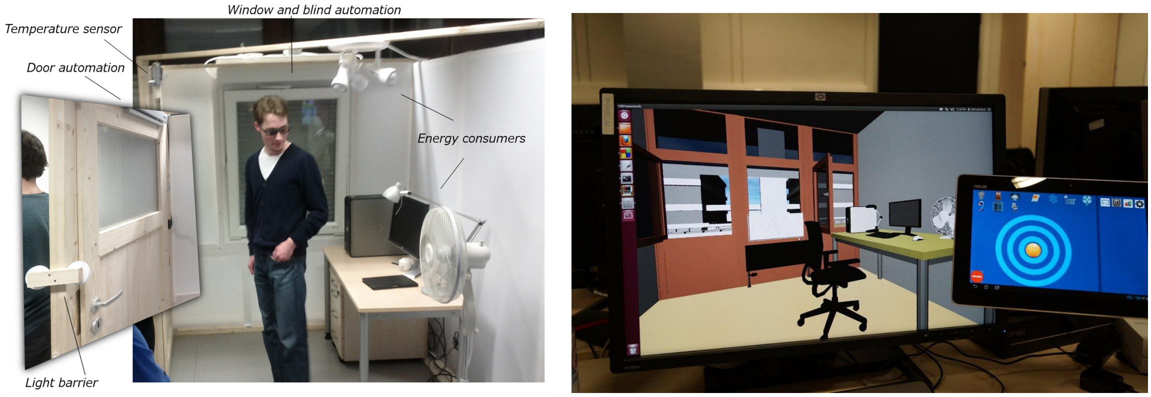

Fig. 5. (a) Energy experience demonstrator; (b) Energy experience virtual world and navigation via tablet

6. Course Evaluation

The course evaluation by the students presented here is based on two questionnaires and the individual project portfolios. Here is an excerpt of the project documentation.

"The VR practical course brought me much closer to the less known for me field of virtual reality. For me was very enlightening to work in an interdisciplinary team, especially since I was the only computer scientist in the group. This made the work sometimes difficult and the learning effect increased. I improved my own understanding through my detailed explanations to the others and also could learn about the perception of the engineer management students. "(Computer science student, WS 2011/12)

"Each team member has learned to work independently, and to share the fruits of this work with the rest of the team. During the planning phase, each member has had the experience to make contact and negotiate with a company, not as a student but as a service recipient. I have also learned how important is the internal agreement, and dealing with interfaces within the group." (Engineering management student, SS 2013)

During each semester a standard questionnaire from the university is made. The most important criteria – the teaching quality index and the overall evaluation are displayed in Table 2. The grade strongly depends on the number of students responding and the project. It is interesting that in the beginning of each new project the grade is lower compared with next semester of the same project.

Table 2. Course evaluation from Karlsruhe Institute of Technology during the semester; Maximum value of teaching quality index is 100 and minimum value is 0. Minimum value of the evaluation is 5 and maximum value is 1; SS – summer semester, WS - winter semester;

Semester	Teaching quality index	Overall evaluation	Number of students
SS 2013 (DRIVE)	100	1.45	11
WS 12/13 (EEVR)	93.3	1.54	13
SS 2013 (DRIVE)	93.8	1.33	6
WS 11/12 (IC^3)	100	1.5	7
SS 2011 (DRIVE)	100	1.29	7
SS 2010 (DRIVE)	-	1.4	7

Table 3. Internal course evaluation over questionnaires (minimum value 5 - maximum value 1); SS – summer semester, WS - winter semester;

Semester	SS2010	WS10/11	SS2011	WS11/12	SS2012	WS12/13	SS2013	Total
Total Feedback	1.8	1.4	1.9	1.6	1.6	1.8	1.3	1.7
Organization	2.1	1.5	2.1	1.4	1.6	2.1	1.5	1.8
Methodology	1.9	1.2	2.0	1.8	1.5	1.7	1.3	1.6
Supervisors	1.3	1.3	1.5	1.2	1.6	1.5	1.2	1.4
Acquired skills	2.0	1.7	2.0	2.0	1.7	1.8	1.3	1.8
Average students grade	1.7	1.0	1.1	1.2	1.1	1.0	1.1	1.2
Number of students	7	3	7	11	7	14	12	61

A questionnaire designed by the course supervisors is conducted at the end of the course after the fourth phase. It provides detailed information about the course organization and methodology, supervisors, acquired skills and gives the possibility for additional comments. In Table 3 the results are summarized for each criteria and each semester until now and also show the correlation between the student's grade and the supervisor's grade in form of total feedback.

The results of the questionnaires for feedback and quality measurement show that our goals are fulfilled and our teaching methodology for a practical course is one successful form for education in virtual reality, where the students enjoy their work.

7. Discussion

In this section we discuss some of the key factors for a successful project according to our experience over the last four years.

The task design is the most important part of the virtual reality practical course. It must be specified very precisely and at the same time have to give the course members freedom to be creative. This is one of the key factors for a successful project. The other issue is the group configuration. Using the information from the interviews, it is easier to define the individual group member's tasks according to their knowledge and interests.

The software platform has to be carefully chosen. It is good if the VR software solution is open source, well documented and has big community. A modular software design facilitates the project extension with new features and the use of specific libraries (for instance sound, physics).

Until now the number of course members was between 7 and 14. In smaller groups it is important that the project manager has a task inside of a group, due to the fact that the effort for management is comparatively small. Status meetings are easier to organize and communication is improved, which yields qualitative and well-structured project results. On the other hand if the group is larger than 10 students, the project management becomes more sophisticated and good control and conflict management is needed. In this case the project manager must only fill the management job and supporting sub-tasks in a group only voluntarily.

A good explanation of the course objectives and organization in the beginning is very important. The students forget about the evaluation phase and come under stress during last two weeks, for instance when writing the documentation. The earlier the interfaces between groups are identified the better is the project plan. This plan is intended to merge the sub-projects' results in the middle of the time period, ensuring that the issues are detected early.

Due to the fast development of new hardware devices, software and applications, it is very important to update the lectures and labs each semester in order to avoid teaching the history of VR. Students interested in this topic or those who are have already listened virtual engineering lectures can quickly lose interest. Up-to date lecture materials, interesting examples and small discussions during the lectures keep students motivated and focused.

8. Conclusion and Outlook

Virtual reality has grown up. Once an exotic field of computer sciences, it is now an important topic for the engineers of tomorrow. Virtual teams are forming all over the world and make use of video and audio communication as well as social media to communicate. VR collaboration platforms are only a step further away. Through the interdisciplinary and international nature of the VR practical course groups, the students learn to know the mindset of the other disciplines and cultures. During the project, they have the opportunity to experiment and learn from their mistakes to ensure that they are better prepared for their professional life. The project tasks from current engineering topics are distributed according to interests and expertise of the practical course member. We have noticed that the challenging tasks of the project strongly motivate the students. The motivation in a team increases so much that most students often work on the project in their spare time.

The coming semesters will see the projects evolve and mature, but also the virtual reality lectures and laboratories will develop even more in the direction of integrated VR solutions in all areas of engineering.

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