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Course Design and Instructional Strategies for Virtual Reality Labs in Engineering Classrooms

K. RAJSEKHAR REDDY¹, O.V. SOWMYA², N. KHADAR VALLI³

Abstract

The price of virtual reality headsets continues to drop, making them more accessible to consumers. Students in higher education also want to be well-prepared for their careers and want to take more courses that put their theoretical knowledge into practice. Moreover, students gain a great deal from opportunities to develop their soft skills.

This article details a curriculum for a virtual reality lab course intended for upper-level students. The course is structured to help students learn about VR by simulating real-world industrial projects, and it has as its stated goals the cultivation of transferable skills like the ability to take a systematic approach to solving real-world engineering problems, work effectively in multidisciplinary teams, and manage one's time effectively. The article also refers to various project examples from the last three years and addresses the significance of the course design, the task definition, and the makeup of the work group for the effective execution of the course.

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

1. Introduction

If we take a look at the products of modern businesses like the electronics or automobile sectors, we can see that complexity is increasing at an alarming rate. Engineers that are well-trained and capable of investigation are necessary to deal with this increased level of complexity. and work well in interdisciplinary teams to resolve complex technical challenges. Strong soft skills are also required for successful teamwork. On the other hand, a fresh crop of engineers is entering higher education, and universities have a responsibility to provide them with the tools they'll need to make a seamless transition to the private sector [1]. When designing engineering curricula, it is important to take into account the actual, ever-changing needs of the business. Virtual reality has several applications, including the medical [3, 4], automotive [4,5], aerospace [6], educational [7, 8], and recreational [9, 10] fields. Our definition of virtual reality is based on Sherman and Craig's [9] human-centered definition of the technology: "... 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." In this concept, the "3 I's" of virtual reality (as coined by Burdea and Coiffet [10])—immersion, interactivity, and imagination—are all given prominent treatment. Multiple input and output devices provide two-way communication between the user and the virtual environment, making virtual reality possible. From a technical standpoint, we consider a virtual environment to be immersive if it supports features like stereoscopic presentations of items at actual size and head-tracking of the user. VR has been given a boost by the entertainment sector, which has helped to drive down the cost of related gear and raise consumer interest. Consumers may now easily buy 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 the MYO wristband. These are not as intense as full-dome VR systems like CAVEs, but they may still be used to educate students the basics of VR without breaking the bank.

Asst.Prof^{1,2,3}

Department of cse

SRINIVASA INSTITUTE OF TECHNOLOGY AND SCIENCE, KADAPA
Chennai- Hyderabad Bypass Road, Ukkayapalli, kadapa -516002

We created a hands-on virtual reality course for college students that mimics the experience of working on a real-world, cross-disciplinary industrial project, thereby allowing us to rise to the challenge of creating industry-focused VR courses. Fifteen students from various majors (including mechanical engineering, mechatronics, computer sciences, physics, and engineering management) have the opportunity to take this course each semester, forming multidisciplinary and frequently multinational groups. The course is designed to assist students learn about VR technology, software, and applications via hands-on exercises and projects. They will work together to solve a challenging problem. They have to think about how the many parts of the project will interact with one another, and then put the pieces together. Time management, cooperation, the ability to work effectively in multidisciplinary settings, and an organized approach to solving real-world engineering challenges are all goals.

In this article, a VR practical course's pedagogical approach is laid out in great depth. The first two chapters cover the same ground in terms of the practical training offered, the supporting infrastructure, and the limiting circumstances. The completed projects showcase the students' accomplishments and serve as models on how to define and allocate tasks. At the end of the paper, the authors analyze the problems that arose during the implementation of the course and offer student feedback on the experience.

2. Related works

One of the first writers to consider the challenges of teaching using VR was Burdea [11]. Among the problems he mentioned was the dearth of textbooks and lectures that could be used in conjunction with virtual reality courses, as well as the need of qualified instructors and specialized lab space. He highlights the rising need for VR professionals and the many applications of the technology as reasons for the necessity of such courses. In 2003 [11], just 148 (3%) universities worldwide provided virtual reality courses; by 2008 [12], that number had increased to 273 institutions. Since then, the availability of virtual reality (VR) courses has grown, with most including lectures and exercises. The few academic virtual reality (VR) practicum courses available today use a variety of instructional approaches.

numerous computer systems and applications. Courses like this are often reserved for computer science majors

3. Infrastructure

This course is held at the Karlsruhe

as an additional resource for their computer graphics studies [13-15].

Stansfield [14] describes an introductory virtual reality course for college students. The course incorporates both lecture-based instruction and practical, real-world application, and it offers the chance to engage in a number of different types of capstone projects. Writing and delivering research papers also helps students improve their communication abilities. The virtual reality (VR) application development framework developed by Miyata et al. [16] is a learning tool. Graduate students participate in a competition by working in multidisciplinary teams to develop virtual reality (VR) apps. Students are inspired to study and grow as a team over the competition's duration. There is a wide variety of material and an emphasis on originality in each of these endeavors. The ideas must originate from the pupils. The vast majority of these programs are games or other forms of amusement.

Zimmerman and Eber [17] offer another example of an interdisciplinary course in which students from different disciplines (art and computer science) work together. The course consists of lectures, demonstrations, research subject presentations, and group laboratories, all of which include both artistic and programming issues. Over the course of the semester, each group uses HMDs and the program WorldUp to build a unique, beautiful virtual world.

When discussing the creative process for products, Fallast and Oberschmid [18] mention a student project that included students from several academic disciplines. Problems arise when student teams across disciplines, cultures, and countries must work together virtually to complete assignments for a corporate sponsor.

Students studying mechanical engineering, mechatronics, electrical engineering, computer sciences, physics, engineering management, and so on will all benefit from this paper's virtual reality practical course. It's part of a larger program that also includes classes in things like virtual engineering, product lifecycle management, information engineering, and even some hands-on CAD work. Our course incorporates a wide range of instructional strategies, including classroom lectures, practical demonstrations, and laboratory exercises.

Institute of Technology in the labs of the Lifecycle Engineering Solution Center (LESC) of the Institute of

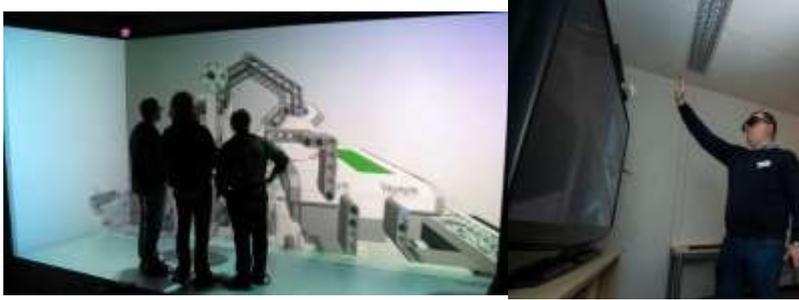


Fig. 1. (a) Three-sided projection in the virtual reality lab in LESC; (b) Energy Experience Lab in LESC

Energy Experience, the third lab, has 3D displays, HMDs, depth cameras, data gloves, and smart gadgets that allow for exploration of accessible virtual reality settings (see Fig. 1). (b). To facilitate the creation of 3D material, the development of applications, and the delivery of courses, a computer lab with powerful workstations is available.

At the beginning of 2010, Dassault Systèmes' 3DVIA Virtools served as the basis for the virtual reality (VR) practical course. Because of the available documentation and the visual programming paradigm it offers, this software is a boon to students who want to create their own programs. Some limitations of 3DVIA Virtools were discovered during development: a lack of a dedicated user base, an ever-increasing level of complexity in the "visible code," and an absence of a solid documentation system. The manual setup of the underlying virtual reality technology was complex and costly.

Our high-end visualization center, LESC, relies on our own VR engine, PolyVR, for both research and education. PolyVR employs the C++ programming language and is built on open-source libraries like OpenSG [19] and OpenGL. Our system relies heavily on OpenSG, which provides scene graph management through a clustering and threading architecture. The VR framework may be expanded with additional features because to its modular design, and the engine develops with each new study. While there is a dearth of written instructions, real-time assistance makes up for it.

The administrative platform ILIAS [20], the version control system GIT, and a number of ticket and project management applications are also utilized throughout the practical session.

4. Teaching methodology

Course participation is open to all graduate and undergraduate students at KIT who are majoring in mechanical engineering, mechatronics, electrical engineering, computer science, physics, or engineering management. The sole stipulation is that they must have finished their fifth semester of

college. Fifteen spots are typically available each semester. There is some wiggle room in the total number of pupils. Four semester credits are earned after a total of 120 hours of work over the course of the semester's 15 weeks. In order to gauge each student's background information, we conduct a short interview with them. This data facilitates the task definition process by ensuring that student preferences are taken into consideration. Motives are stoked, productivity is increased, and certain skillsets are honed as a consequence.

4.1. Course design

There are four interconnected stages of the practical course that use a variety of approaches to instruction (see Table 1). Assuming that all students have a similar academic background, the first three weeks of the course consist of lectures and demos that introduce the students to virtual reality. Brief classroom discussions on "Definition and use of VR," "Hardware for VR," and "Software methodologies and solutions for VR," are interspersed with hands-on lab exercises. Students are able to concentrate more intently throughout class and leave less confused about the VR topics they've been introduced to.

When we go on to the next step, we'll be doing hands-on lab work using software designed for certain jobs. Blender, CAD programs like CATIA, and virtual reality (VR) solutions like 3DVIA Virtools and PolyVR are often introduced via hands-on laboratories.

The third and final stage (lasting about 9 weeks) consists of collaborative projects undertaken by smaller groups. In the first two weeks of the phase, participants are divided into groups and given their tasks. The course supervisors write the assignment specifications with the students' needs and the course's aims in mind. There is an additional, voluntary activity for each group to do. Members of the group vote on who will take on the subtask.

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

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

Mechanical engineering, computer science, and engineering management students often work together in multidisciplinary groups that aim to replicate the dynamics of real-world industrial projects. Figure 2 depicts the organizational structure and student-teacher interaction during the duration of the course (a). The students have two weeks to do research and make preparations after receiving the work description. The milestone schedule, cost estimates, and proposed methods of solving the problems are all presented once that time period has passed. Early identification of the interfaces between the groups and sub-tasks is crucial during the planning phase. The participants in a practical course often get together every two weeks to review the project's development and solve any difficulties that have arisen. In this stage, participants have complete autonomy over the selection of software tools for assisting with projects, such as project management, communication, and ticketing systems.

project manager's responsibilities include setting goals, developing a schedule, allocating resources, monitoring progress, resolving conflicts, and communicating with the course instructors. Some projects also include a post for a technical leader.

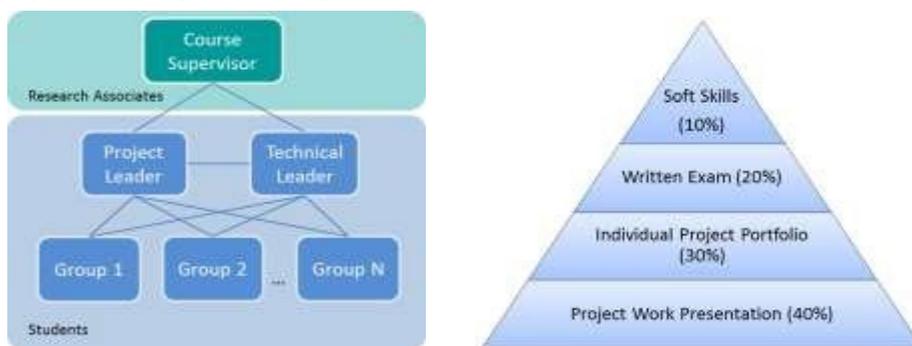


Fig. 2. (a) Hierarchy and communication paths for all course members; (b) Evaluation components

Starting in the third phase with a continual assessment of social skills, the VR practical course incorporates a complicated evaluation, as shown in Fig. 2. (b). The presentation of the project's effort and outcomes is a crucial part. Students may develop their oral and written communication abilities by discussing their projects under a time limit. The following section focuses on a person's "personal project portfolio." There are two goals for this writing. In the first semester, students practice writing project documentation that will later serve as a resource in subsequent terms. The projects are long-lasting and may be completed over the course of many academic years. Portfolios detail the individual's learning progress and reflect on their own reasons for completing the assignment. The project manager's portfolio takes the form of a report detailing the whole project's outcomes. The last test is a brief written recall of material. component. Prior to the start of class, students will be asked to define two key concepts that

will be covered in the course's introductory lectures and labs.

5. Projects

5.1. Immersive driving simulator (DRIVE)

As shown in Fig. 3, the initial prototype was a mixed-reality driving simulator that was developed over the course of many semesters (a). The visual output gear consists of a cluster of computers and a powerwall with an ART tracking system for head tracking. Students constructed a seat box complete with an actual automobile seat and interfaced it with a Logitech G25 gaming controller (steering wheel, pedals and gear). The 3DVIA Virtools program was used to create the solution. The students had to create

a digital setting that had an automobile model in three dimensions, a racetrack, and realistic environmental, climatic, and auditory elements. The mechanics and realistic driving simulation were the most vital elements (e.g. collision detection). We utilized 3DVIA Virtools' physics bundle for this, making sure that when the weather changed, the friction settings and the textures changed as well.

Students learnt how to use a computer cluster to create a virtual camera, set up head tracking, and configure the visual output.

In order to make the simulation more realistic, each component was refined over the course of many semesters. Over time, the driving simulation's surroundings became more intricate, and manual transmissions were included..



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

See Figure 3 for further details on how the Daimler AG firm contributed an actual Smart Fortwo to the development of the simulator's second iteration (b). The difficulty lay in adding an automobile to the virtual environment. This was completed in only two semesters thanks to a variety of methods. The first strategy used the already-existing software interface by embedding a Logitech sensor in the vehicle. The next semester, the students used reverse engineering techniques to access the vehicle's CAN-bus system. Transmission of signals between the automobile and the computer, and vice versa, is now feasible. All of the standard controls and displays in the cockpit may now be accessed in this manner. As an alternative to 3DVIA Virtools and its many flaws, a new program was written using the VR framework PolyVR and the simulation program Matlab/Simulink. It was necessary to redo work like simulation visualization and developing a virtual setting. The vehicle's 5.1-channel sound system was used to create the ambience of the ride. As a result of issues that arose while using the vehicle as a VR input device, namely the necessity for head tracking, the students created to aid in collecting early feedback on product design based on user preferences.

created a system for doing so that is based on the Kinect depth camera. The fully lifelike driving simulator will be upgraded even more in the next semesters.

5.2. Immersive car cockpit configurator (IC³)

During the hands-on portion of the virtual reality training, students also created a realistic automobile cockpit configurator (see Fig. 4). With the help of the VR lab's three-sided stereo projection equipment, we were able to set up the configurator. The input interface consisted of an optical tracking system called ART for head tracking and an interaction device called a flystick2. Students in machine engineering and engineering management were split into two groups and tasked with doing market research using questionnaires and then utilizing computer-aided design (CAD) software to build many cockpit designs. The product configurator was

There are a total of six.

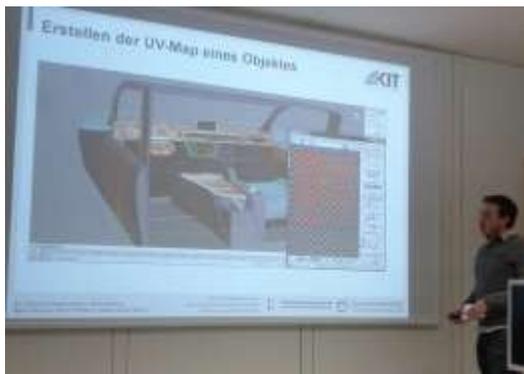


Fig. 4. (a) Immersive car cockpit configurator (IC³) project; (b) Student presentation on IC³ project

In order to import the 3D models and create the configurator and the interaction in the virtual world, a group of computer science and engineering management students worked together. After the change was made, researchers analyzed the data statistically. Machine engineers, computer scientists, and engineering managers may all learn from this project's example of how to best organize their work into cohesive teams and tasks.

5.3. Energy experience VR demonstrator (EEVR)

More and more people are interested in studying how to reduce energy use and waste. We developed a VR software to mimic the actions of people in a common area (such as an office) and display the resulting information on the amount of energy used by the

building. Here, cellphones and tablets were used to connect a virtual demonstration with real-world sensors and actuators (see Fig. 5). The visual output is a 3D passive TV set, which serves as the virtual demonstration. Using a very accurate 3D model of our school's structure created in Blender, we were able to add user behavior and animations in PolyVR. Different sensors (temperature, humidity, CO₂) and actuators are installed in the demonstrator's physical component (for opening and closing door or window, switching on and off lights or the computer). You may operate both halves of the system from the same tablet. The sensor data was shown in the virtual world using a number of different 3D and 4D visualization paradigms, together referred to as immersive visual data mining.

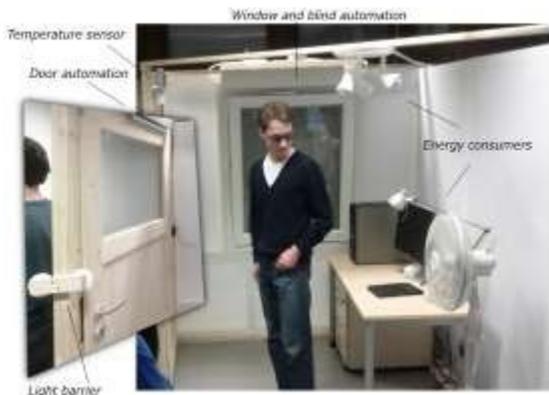


Fig. 5. (a) Energy experience demonstrator; (b) Energy experience virtual world and navigation via tablet

6. Course Evaluation

The students' course evaluations shown here were compiled using data from two surveys and their final project portfolios. The documentation for this project is shown here in its entirety.

The VR practical training was a great introduction to the world of virtual reality, which was previously unfamiliar to me. Working in an interdisciplinary team, particularly as the lone computer scientist, was a very educational experience for me. This boosted the learning impact and made the assignment more challenging at times. In the process of clarifying things for my classmates, I was able to deepen my own comprehension and get insight into the engineer management students' point of view. (College freshman majoring in computing, AY 2011/2012)

"Everyone on the squad has figured out how to do their own thing and then pitch in to help the rest of the group.

Each team member has been in a position to initiate contact with and negotiate terms with a corporation throughout the planning process, rather than just as a student. Internal agreement and navigating group interfaces are also new areas of expertise for me. (2013 Summer Session undergrad in Engineering Management)

Every semester, the school creates a standard questionnaire to assess student satisfaction. Table 2 displays the results of the most relevant categories, including the teaching quality index and the overall rating. Number of participants and quality of project are major factors in determining final grade. It's fascinating to see how grades drop at the start of a new project but then rise the following semester.

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

At the conclusion of the course, after the fourth phase, participants will complete a questionnaire developed by the course supervisors. It includes specifics about course structure and technique, instructors, knowledge gained, and open discussion space. The cumulative input from both the student and supervisor is given in Table 3, along with the outcomes for each criterion and semester to date. Students' positive responses to our evaluation and feedback surveys indicate that we have achieved our aims and that our practical course teaching approach is a viable option for educating using VR.

7. Discussion

Based on our four years of expertise, we'll be discussing

some of the most important aspects of a successful project in this area.

The assignment design is the most significant aspect of the virtual reality practical training. It has to be very detailed, but also open to interpretation by the students in the class. It's important since it's a prerequisite for a well-executed project. The group structure is also a problem. Information gathered from the interviews may be used to assign tasks to group members based on their areas of expertise and areas of interest. The software platform needs to be carefully picked. The ideal virtual reality software solution would be freely available, be fully documented, and have a sizable user base. When a software project is built with modularity in mind, adding

new features and incorporating specialized libraries may be accomplished with ease (for instance sound, physics). Until date the number of course members ranged between 7 and 14. Due to the low overhead involved in managing a small group, it is essential that the project manager be given some kind of internal role. Status meetings are simpler to plan and communication is enhanced, which provides qualitative and well-structured project outputs. On the other hand if the group is greater than 10 pupils, the project management gets more advanced and effective control and conflict management is essential. Here, the project manager's involvement in the group's management and supporting roles is entirely optional.

A solid description of the course goals and structure at the beginning is highly crucial. The students stress excessively in the last two weeks, for example, while drafting the paperwork, and forget about the assessment phase altogether. Identifying these points of contact early on in the project planning process is essential. This strategy is meant to combine the sub-projects' findings midway through the time frame, which will allow for early detection of problems.

It is crucial to revise the lectures and labs every semester to avoid teaching the history of VR due to the rapid development of new hardware devices, software, and applications. Even enthusiastic students, or those who have listened to such virtual engineering lectures before, may rapidly lose interest in the material. Modern teaching materials, engaging examples, and casual classroom dialogues help students stay engaged and attentive.

8. Conclusion and Outlook

The technological capabilities of virtual reality have matured. When compared to other areas of computer science, this one may seem foreign, yet it is becoming more relevant for the engineers of the future. Video and audio conferencing, as well as online forums and other social media, are all tools used by the increasingly common virtual teams. Virtual reality (VR) collaboration systems are on the horizon. Students get exposure to new fields and cultures via the multinational and multidisciplinary character of VR practical course groups. They will be more equipped for the professional world after participating in the project because of the freedom to experiment and the lessons learned from those experiments. Current engineering topics are divided among the practical course participants' areas of interest and skill. To our surprise, we found that the students were very motivated by the project's rigorous requirements. When working on a group project, students get so inspired that they often put in extra time outside of class.

The projects will continue to grow and mature over the next several semesters, and the virtual reality lectures

and labs will continue to advance in the direction of fully integrated VR solutions throughout all of engineering.

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