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A Virtual Reality Course Using EON Reality: Students' Experiences

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Abstract

This paper describes students' experiences in a required first-year graduate-level one-semester three credit-hour mechatronics engineering course on virtual reality (VR). The course included lectures with assignments and tests, lab examples, lab exercises, and a final VR project. The VR lab environment was provided by EON Reality. It included one large single screen computer assisted virtual environment (CAVE) EON Icatcher and EON Professional integrated development environment (IDE) software. Two groups of graduate students enrolled in the course for two consecutive years provided feedback through surveys, discussions, and informal interviews. Students gained practical experience with designing VR systems and VR environments, appreciated the labs, and were excited about their VR projects.

Introduction

The demand for new knowledge content is high in engineering education practice at the graduate level. It is expected that the graduate courses lead, or at least reflect, the current state of technological developments and scientific discoveries. To stay competitive and current, curriculum designers are under constant pressure to incorporate the newest technologies in the classroom either as new course modules or as entirely new courses. Textbooks and laboratory guides for these courses either don't exist yet or are out-of-date due to fast-paced changes in technology, low textbook volumes, and the significant expertise required to write them.

The VR course at Colorado State University - Pueblo was designed to introduce graduate students to VR concepts through lectures and practical exercises culminating in a mechatronics-related VR project. However, the developers of this VR course had to overcome a number of challenges. The Sherman and Craig [1] textbook chosen for the course is technologically outdated (published in 2003), but is well organized and provides good explanations of various key VR concepts. The book also seemed more student-friendly than the Burdea and Coiffet [2] textbook (also published in 2003). The VR course was first offered in 2014. Originally, the labs were based on C++, OpenGL, and Virtual Reality Modeling Language (VRML). In 2015 the labs revolved around a haptic device, the Phantom Omni by SenSable Technologies Inc. that was donated to the Department of Engineering. At the end of 2015, the department purchased an EON Reality Icatcher VR system. The first set of labs with this system was offered in Fall 2016. The EON Reality system included a book [3] describing the software in detail. While informative, the book was three versions behind the current software version (many examples described in the book did not work with the current version of the software). Also, the book was discontinued and was prohibitively expensive. Finally, the author attended a 10-day training session offered remotely by EON Reality staff to develop expertise and learn advanced features of EON Professional. The above facts and activities greatly influenced VR labs development for the VR course.

This paper mainly describes students' experiences with a novel required first-year graduate level course on virtual reality (VR) taught at our Master of Science in Engineering with Mechatronics

Emphasis (MS-Mechatronics) program. This three credit-hour semester-long course consists of lectures, laboratory examples, exercises, and projects. Since this work deals with human subjects, all student work, including pictures, survey responses, and informal interview responses, are presented with their permission. An Institutional Review Board (IRB) approval under the "exempt" review category was obtained from the university's IRB for the survey and the interviews.

What follows are sections on previous work, curricular context, description of the VR hardware with associated integrated development environment (IDE), and educational experiences for the students. The results of a short questionnaire and informal interviews with students are described and analyzed.

Previous Work

Hands-on experiences and projects are important parts of learning. For example, Kolb's Experiential Learning Cycle [4] learning theory claims that learners learn best, regardless of their preferred learning style, when they follow a cycle/spiral consisting of four steps: experiencing, watching, thinking/modeling, and applying/doing. Thus, both modeling and doing are crucial parts of learning. Kolb's learning cycle has been used in engineering education including civil [5-7], mechanical [7], chemical [5, 6, 8], industrial [9], aeronautical [7], and manufacturing [5, 6, 10] engineering curricula.

Most of the VR educational research is concerned with applications of VR environments in classrooms and labs, not the education of the creators of VR experiences. For example, El-Mounayri *et al.* [11] describe an immersive VR environment to learn how to operate a computer numerical control (CNC) milling machine in a graduate course, while Syed *et al.* [12] use a VR environment to demonstrate grinding and milling operations in a junior-level manufacturing course in a mechanical engineering program. Peng, Isaac, and Wilkins [13] use a PowerWall VR system to deliver simulations on nanoscale and nanotube topics for a course on photonic and electronic materials and devices. Chatuverdi *et al.* [14] created a VR experiment for a thermo-fluids lab course and used it as a pre-physical experiment. Ari-Gur *et al.* [15] developed a set of VR experiments using EON Studio, Unity3D, and LabVIEW for various educational uses. Tang, Shetty, and Chen [16] apply VR games to increase students' reading and problem-solving skills in an electrical and computer engineering curriculum. Madathil *et al.* [17] implemented a VR environment to teach safety in manufacturing. They concluded that the student perceived improvement in learning was significant even though there was no actual improvement. Also, Nippert and Um [18], who compared a VR experiment and an equivalent physical experiment in a freshmen-level introductory engineering course, concluded that the learning gain was equal in both cases. This work addresses a gap in educational literature by describing a course where students learn how to use VR tools (EON Professional) to create virtual environments.

Curricular Context

The VR course described in this work is a required one-semester three credit-hour first-year graduate-level course in an MS mechatronics engineering program. Even though the main emphasis of this work is on students' experiences, the course is described in sufficient detail for possible adoption. Based on the course learning outcomes, a set of general topics, shown in Table 1, are developed. Chapter references in Table 1 refer to the textbook [1]. The course lectures and regular labs are scheduled twice a week. All of the graduate courses in the engineering department are scheduled starting at 4:00 PM and later to allow the engineers from industry to attend classes. The VR lecture only sessions are scheduled for 1.5 hours on Tuesdays. On Thursdays, half-an-hour lectures on lab topics are presented and discussed and then two-hour (or longer) labs are conducted. The instructor implemented the inverted classroom method where students read the assigned material before the class meetings and then discuss the topics in class. To enforce students' preparations, six short (two to five minutes) in-class one-question quizzes are administered and graded (six percentage points total). The quizzes mostly assess students' vocabulary based on the assigned reading. They contain questions asking students to define typical VR terms like avatar, CAVE, virtual world, rendering, rasterization, culling, field of view, field or regard, visual depth cues, storyboard, localization, ambisonics, kinesthesia, mimesis, diegesis, etc. The two take-home exams (the midterm in week 8 and the final in week 15), each worth 20 percent, primarily test students' knowledge of the VR concepts. They include questions dealing with more comprehensive VR topics like visual depth cues, position tracking methods, possible causes of simulator sickness, geometrically-based and nongeometrically-based rendering systems, etc. Additionally, in two homework assignments, each worth two percentage points, the students are asked to (1) find and print an example of visual cues and to (2) create a storyboard with 5 to 6 scenes of anything they want. Finally, for individual projects (worth 50 percent), the students are instructed to create VR environments/experiences related to mechatronics and based on their proposals provided previously as storyboards. The individual projects are created outside the normal class hours. Grades were not curved. They followed a typical grading pattern with 60% equal to a D, and a jump every 10 percentage points above that.

Course outcomes. At the end of the VR course, students are expected to have the following knowledge, attitudes or skills:

1. Understanding of virtual reality concepts, components, and systems (measured via two tests and six quizzes)
2. Ability to create a virtual environment (measured through labs, homework, and individual projects)
3. Ability to implement and use virtual mechatronics devices and assemblies as a part of the engineering design process (measured by some labs and individual projects)
4. Ability to implement and use virtual environments in mechatronics simulations (measured through labs and individual projects)

Lab Work

The lab experience consists of a set of in-house developed lab lessons with examples and exercises and a mechatronics-related VR project. The labs shown in Table 2 are developed based on the 10-day training session conducted by EON Reality personnel and the Justice *et al.* [3] textbook.

Table 1. VR Course General Topics

Topic	No. of Hours	Course Outcomes
Introduction to VR and AR (Ch1)	3	1
VR Medium (Ch2)	3	1 and 2
VR Systems: Inputs (Ch3)	3	1 and 2
VR Systems: Outputs (Ch4)	3	1, 2, and 3
Rendering (Ch5)	3	1, 2, and 3
Interacting with VR and Cyberspace (Ch6)	3	1 and 2
Demos: EON Reality Icatcher, Oculus Rift, Vive, etc.	1	2 and 3
EON Professional + programming	24	1 through 4
EON-based VR project presentations	1	1 through 4
Exams and discussions of exams	1	1
Total hours	**45**	

Table 2. VR Lab Lessons and Exercises

Lab	Title	No. of Hours	Course Outcomes
1	Getting to Know the EON System	2	1 and 2
2	Fundamentals of Developing Active 3D Environments	4	2
3	Organizing, Running, and Saving EON Applications	2	2
4	Node Interaction, Part I and II	4	2 and 4
5	Importing Objects into EON	2	2 and 3
6	Physical Nodes in EON	4	2, 3, and 4
7	Scripting in EON, Part I, II, and III	6	2, 3, and 4

Next, the VR system's hardware and software are described but only to provide the environmental context in which the students designed their projects.

CAVE Hardware

EON Icatcher is the CAVE used in the VR course labs. Figure 1 shows students performing lab exercises in the CAVE, while Figure 2 shows some of the systems hardware components. The CAVE consists of a small classroom without windows and an EON Icatcher High Definition (HD) VR system. The system comprises an in-ceiling front-mounted short focal length 3D digital light processing (DLP) active stereo projector, a large projector screen ($94^1/2$" x 168"), three Vicon infrared (IR) tracking cameras, ten VR radiofrequency (RF) glasses, a graphic server, a digital sound system, and interactive devices such as a joystick, 3D mouse, wireless keyboard, wand, etc.

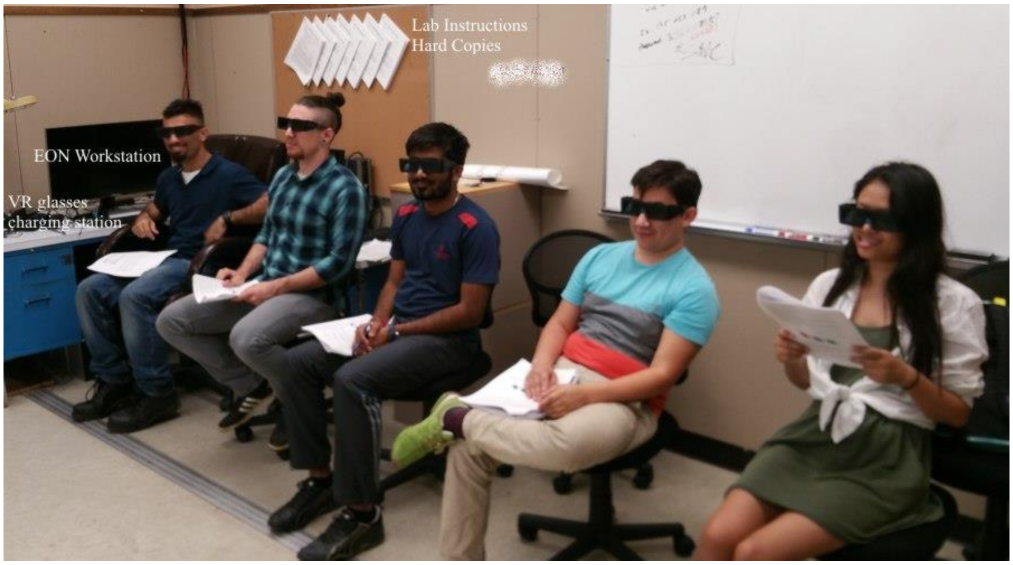


Figure 1. Students Observing a Simulation in EON Reality Icatcher

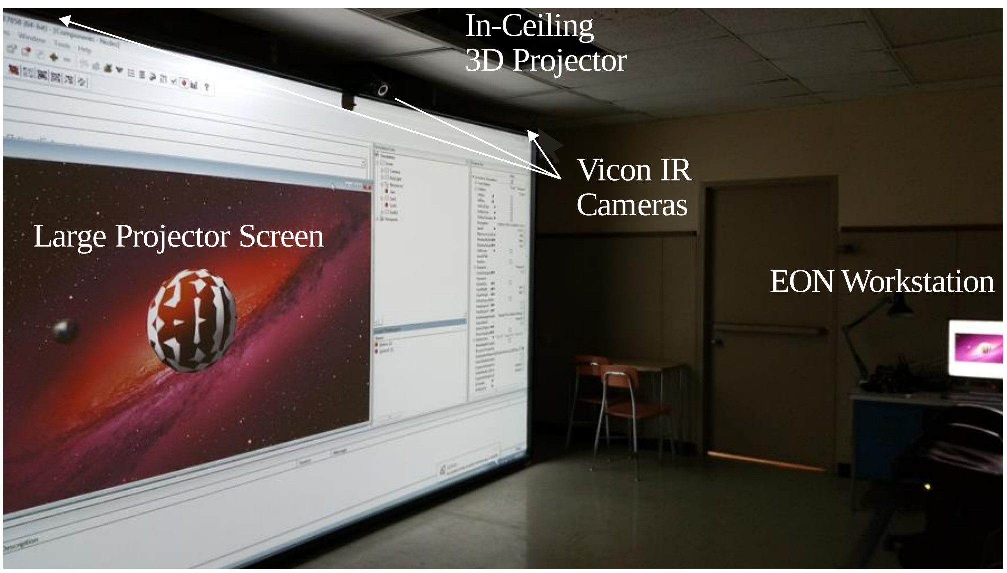


Figure 2. VR System Hardware Components

EON Professional IDE

An IDE or authoring software platform, EON Professional, is included with the EON Icatcher hardware platform. The EON Reality software suite consists of EON Professional, EON Dynamic Load for dynamically loading and unloading files during simulation runs, EON software development kit (SDK) for creating nodes and fields using C++, and EON Raptor for importing 3D objects from Autodesk's 3ds Max. Figure 3 shows a screenshot of EON Professional running a student's simulation.

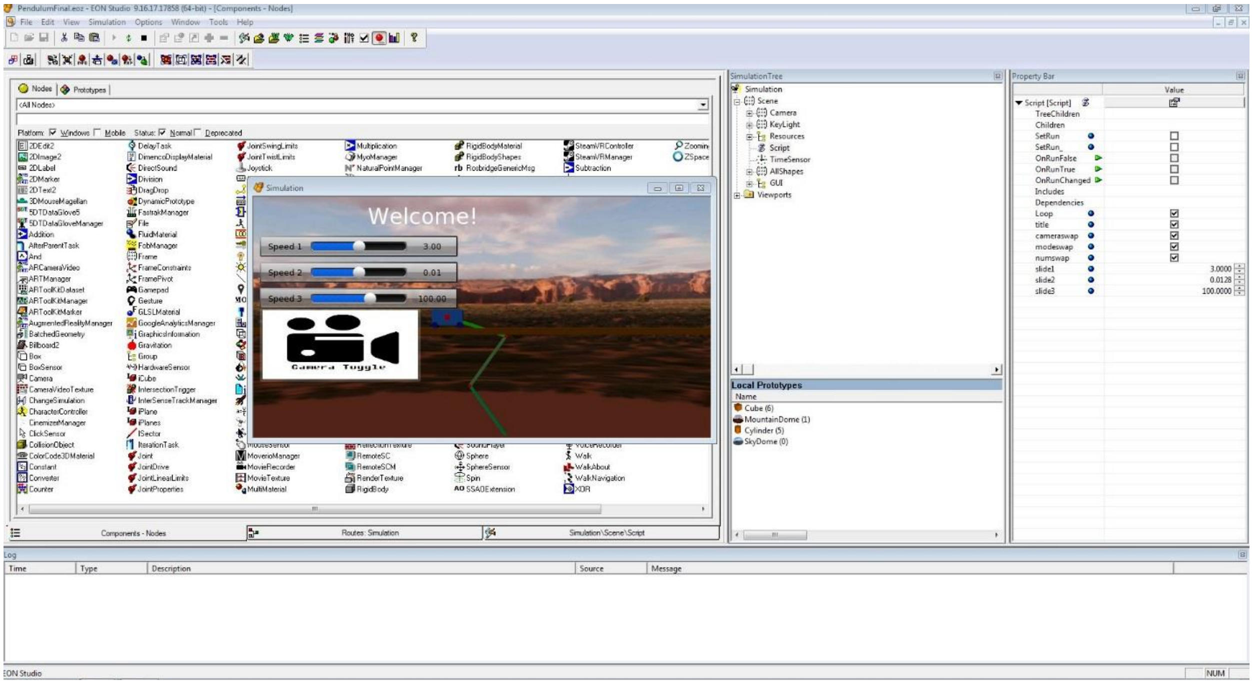


Figure 3. Screenshot of EON Professional with a Student's Simulation Running

Figure 4 shows a screenshot of a VR project simulation window. Simulations can run in a window or full screen. When a simulation is running in the stereoscopic mode on the large projector screen, the graphic station's monitor must be turned off, or both displays would flicker. This posed a problem for some students that erroneously concluded that the system is not working properly.

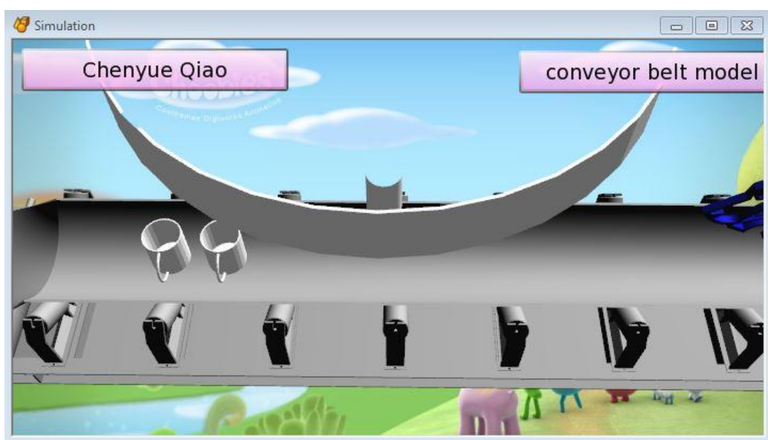
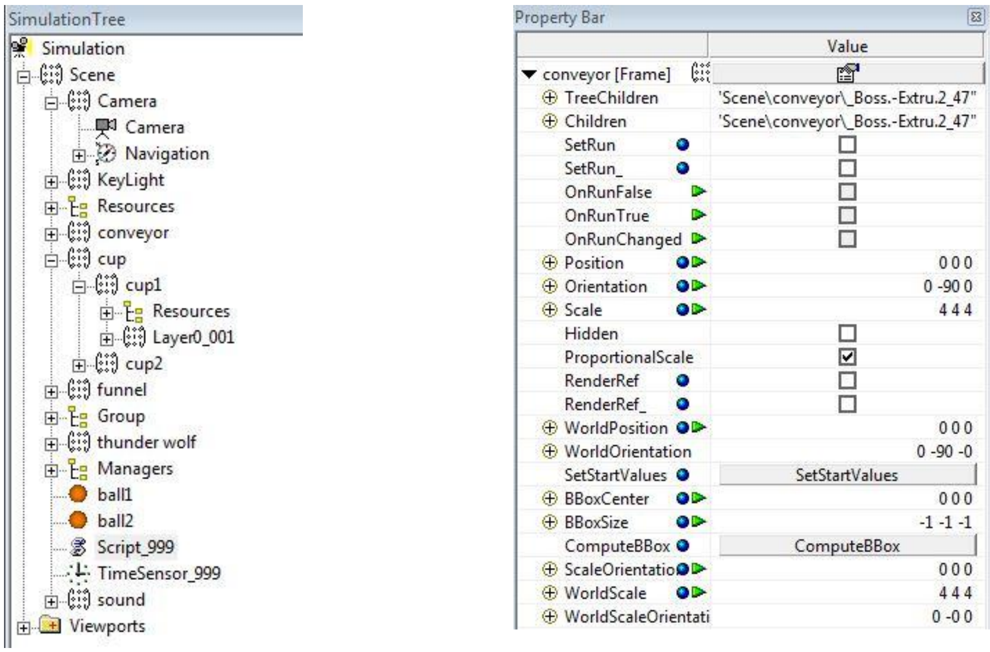


Figure 4. Screenshot of a Student's Simulation Window

Programming in the EON Professional IDE is performed by using windows that open when EON Professional starts. First, a set of nodes and prototypes from the Components window are dragged to the Simulation Tree. As nodes and/or prototypes are added, their properties are adjusted according to the design requirements. After this, the Routes Simulation window (a graphic editor) is used to create relationships between nodes and prototypes. These relationships are event-driven and interactive. The nodes are dragged from the Simulation Tree window into the Routes Simulation window and connected by routes (similar to the LabVIEW graphical programming environment but more complex). Figure 5 shows two related windows, the Simulation Tree window and the Property Bar window (corresponding to the “conveyor” frame in the Simulation Tree), while Figure 6 shows an example of the Routes Simulation window. As shown, routes can quickly become complex when programming more complicated scenes and actions. In such cases, textual programming becomes a better programming choice.



a b

Figure 5. Screenshot of (a) Simulation Tree Window and (b) Property Bar Window

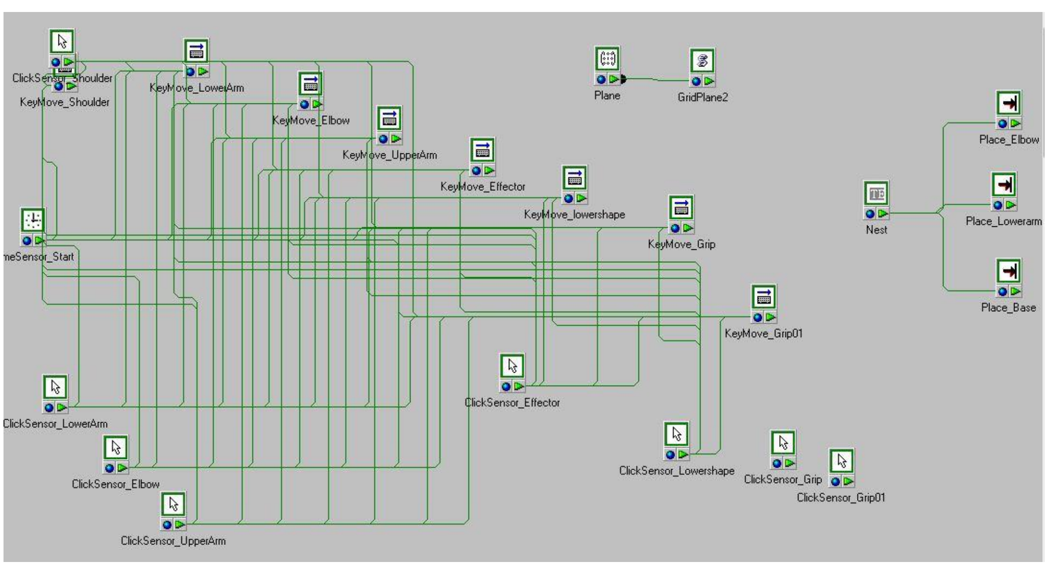


Figure 6. Screenshot Example of the Routes Simulation Window

Textual programming is supported via the Script node that uses JavaScript, Jscript, or VBScript. Figure 7 shows a screenshot of the Script Editor where JavaScript is used.

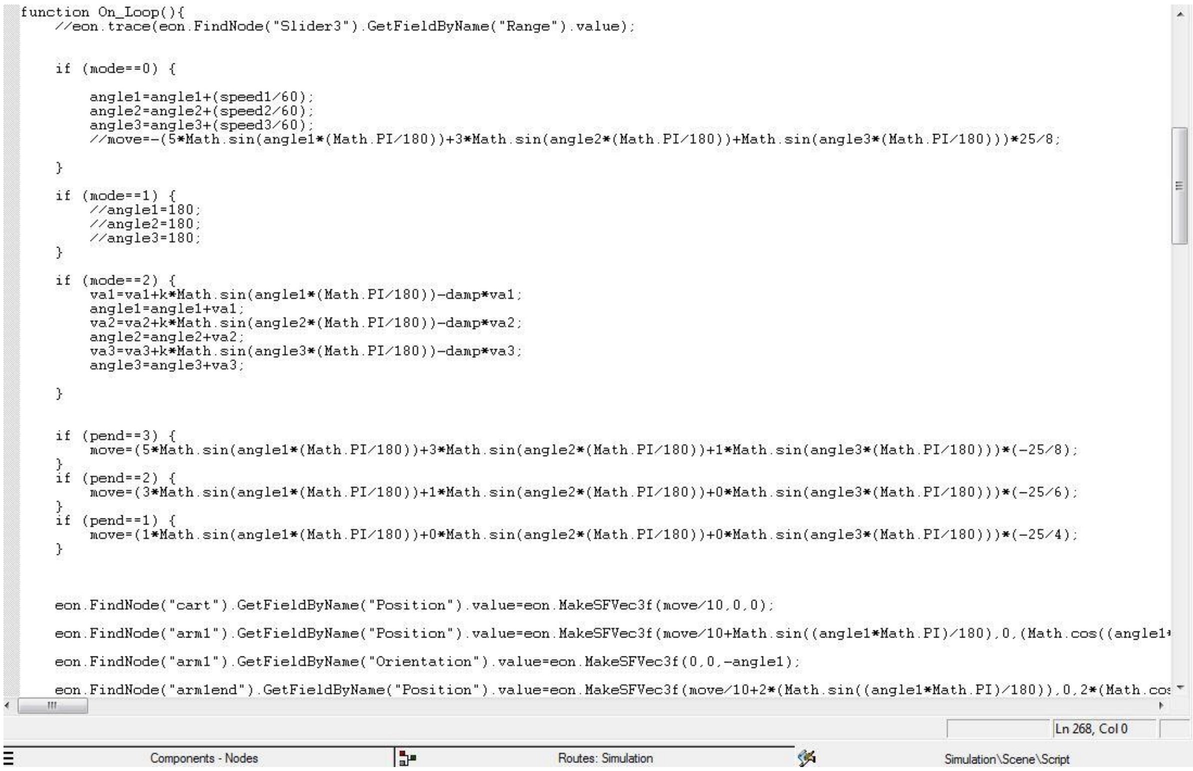


Figure 7. Screenshot of the Script Editor

Students' Educational Experience

Two groups of first-year graduate students (Fall 2016 and Fall 2017) enrolled in the course. Most of the laboratory examples and exercises were developed during the 2015-2016 school year. Apart from these examples (mostly performed during the class time), exercises (mostly performed outside the scheduled class/lab time), and homework assignments, students were asked to create mechatronics-related VR experiences for projects of their own choosing. The projects served as a powerful learning engine as well as an evaluation of students' knowledge and skill gains. Students created their own storyboards, built their virtual worlds using VR concepts and EON Professional techniques, and programmed in a graphical as well as a textual language. As evidenced by students' informal interviews, their motivation also increased as they were creating their projects. Finally, the students were involved in a few outreach activities showing their work to other students, faculty, administrators, and the public.

An example of a student's storyboard with six scenes is illustrated in Figure 8. Two additional examples are placed in the Appendix. While a lab example is depicted in Figure 2, a snapshot of a VR project is depicted in Figure 9. Two additional VR projects are presented in the Appendix.

Figure 8. An Example of a Storyboard

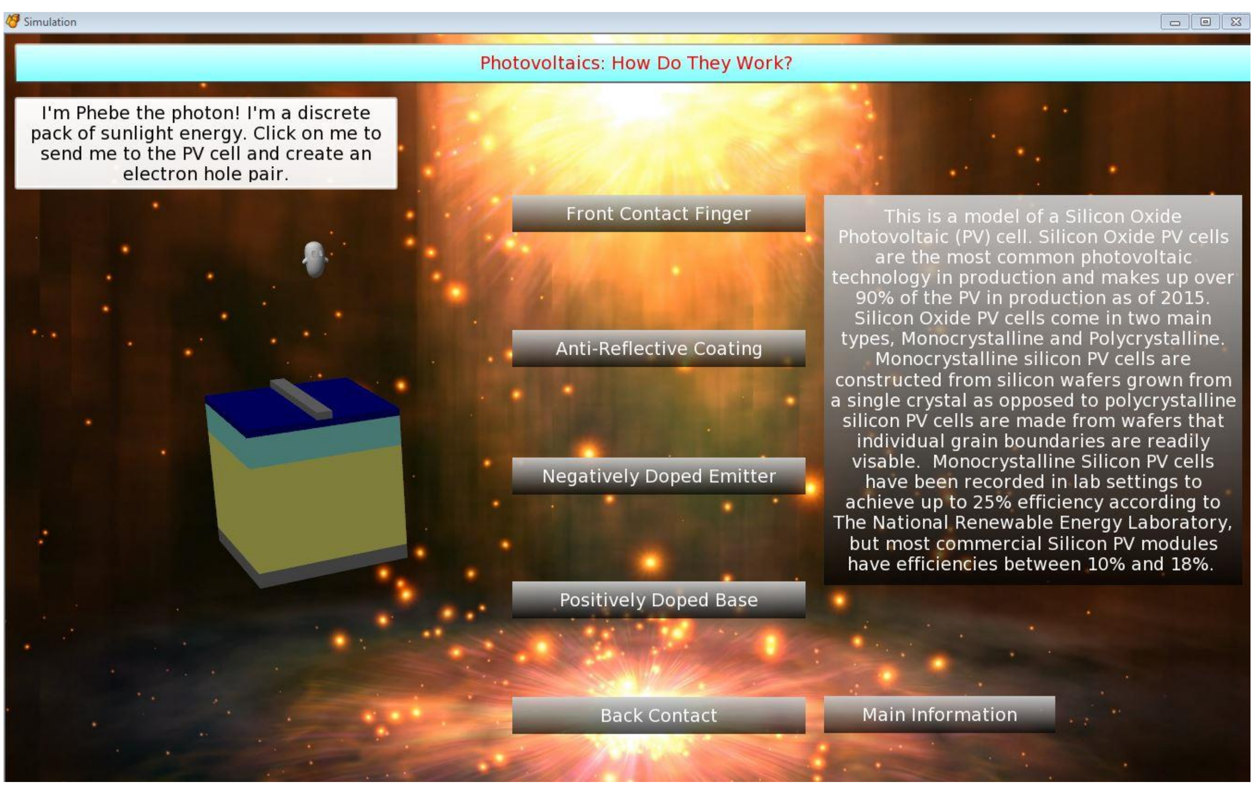


Figure 9. Snapshot of a Student's VR Project

Evaluation and Assessment of Students' Knowledge Gains, Attitudes, and Perceptions

Students' knowledge gains were measured through two tests, six quizzes, and successful completion of VR lab examples, exercises, and VR projects. All students successfully completed the course. The average score on the two major take-home exams (the midterm and the final) was 97.3. The homework assignments score average was 95. One student misinterpreted the storyboard requirements and received a lower grade. The six short quizzes were related to the assigned textbook chapter readings (six chapters) and the inverted classroom teaching approach. The students in the second group (Fall 2017) didn't do well on the first quiz (defining "avatar"), mostly because some of them didn't have their books yet and the others just received their books the day before the quiz. Thus, the quiz dealing with Chapter 1 was repeated a week later asking students to explain the difference between telepresence and teleoperation. This time, all students correctly answered the question. Most of the students answered correctly the other five quizzes.

The lab examples are performed collectively during the assigned lab hours. The students take turns every 15 minutes in round-robin fashion commanding the VR computer. Figure 1 shows a student at the VR computer on the far left, a student reading the lab steps besides him to the right, and the rest of the students checking their work while looking at the large projector screen.

Lab exercises consist of VR design problems that students solve individually outside the scheduled lab time. Some examples of the design problems are (a) a multiple robot cell, (b) a living room with a working DVD player and a TV screen, (c) the Solar System, and (d) a game where the user jumps from one plate to another as the plates are moving and rotating. The completion of the lab examples and the lab exercises is required for starting the VR project.

All VR projects start with students' proposals that must include a storyboard (or a list of actions), a list of inputs and outputs, a tracking system (if needed), and a CAD model (if needed). The only limitation imposed is that each VR project must be somehow related to mechatronics. This limitation was not enforced for the first group of students (Fall 2016) resulting in VR projects addressing railroad-crossing safety, mechanics experiments with friction, and two robotic snowmen dancing. In Fall 2017, all students were able to finish their VR projects demonstrating mastery of VR programming with EON Professional.

Two instruments were developed to measure students' attitudes and perceptions: a questionnaire and a set of informal interviews and discussions with the students. The questionnaire was administered and the results evaluated for two groups of first-year graduate students. However, since the first group only had three students and the second group only had five students, the questionnaire results were combined. The questionnaire consists of six questions rated on a Likert scale from 1 to 5 and four open-ended questions. Questionnaires were administered immediately after the students' presentations of VR projects. The questionnaire is shown in Figure 10.

Figure 11 includes probability distribution functions (pdf) for the first six questions. Only Questions 4 (average 4.0, standard dev. 0.76) and Question 5 (average 3.75, standard dev. 0.71) seem to be Gaussian. There were no negative results recorded. Question 1 suggests that all the students were excited about the VR course. Question 2 reinforces the students' perception that they learn much when immersed in a VR environment (either as users or developers). Question 5 dealt with students' inconvenience level when using the only one copy of the software available. Some of the students adapted well by using a demo-version of the software (30 day limit) to finish their VR projects while others used TeamViewer to access the VR workstation remotely. This result may serve as a justification for purchasing additional EON Professional licenses.

EN 507 Virtual Reality Students' Attitudes and Perceptions Questionnaire

Please rate the following six questions

1. The VR class was _________.
   1 = really boring, 2 = a little boring, 3 = typical, 4 = somewhat exciting, 5 = very exciting
2. I learned _________ in this class.
   1 = nothing, 2 = little, 3 = something, 4 = much, 5 = very much
3. EON-based VR labs were __________ in my understanding of VR principles and procedures. 1 = detrimental, 2 = not helpful, 3 = neither helpful nor detrimental, 4 = helpful, 5 = very helpful
4. Through labs, homework assignments, and the VR project I became _________ with the VR technology.
   1 = less proficient, 2 = somewhat less proficient, 3 = neither less nor more proficient, 4 = somewhat proficient, 5 = very proficient
5. We had only one copy of the software in the VR lab. I __________.
   1 = did not adapt at all, 2 = did not adapt well, 3 = am unsure how well I adapted, 4 = adapted well, 5 = I adapted very well
6. The developed lab notes were ___________in learning the EON Professional software package.
   1 = very ineffective, 2 = somewhat ineffective, 3 = neither ineffective nor effective, 4 = somewhat effective, 5 = very effective

Please comment on the VR course/lab:

7. What is it that you liked the most about the course?
8. Which part of the course/topic was the easiest/hardest for you?
9. What is it that you think can be improved?
10. Any other thoughts?

Figure 10. Students' Attitudes and Perceptions Questionnaire

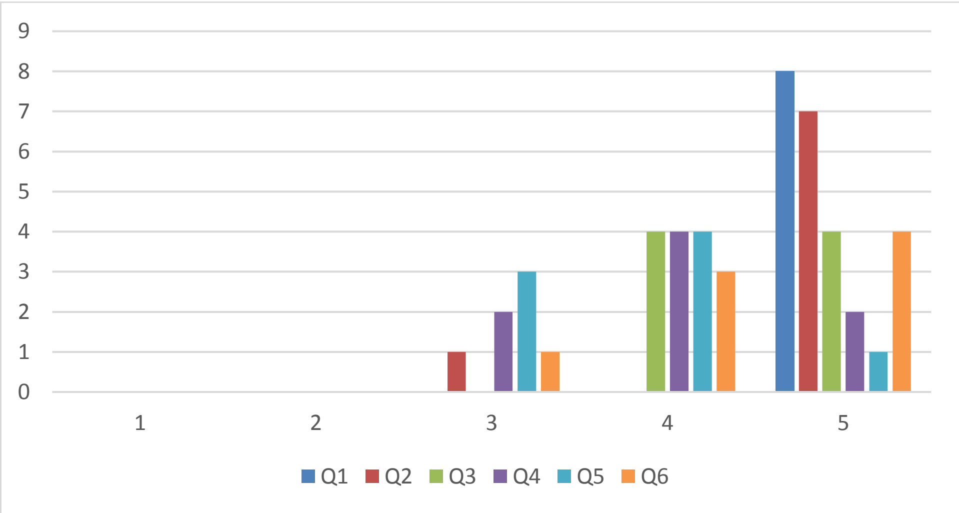


Figure 11. Survey Results for Questions 1 - 6

Questions 7 through 10 are open-ended questions that were designed to allow students to think about VR in a more general sense. Question 7 was written in a positively biased manner because it was meant to be a motivational tool, not a part of the assessment. While self-reflections are important components of experiential learning [4-6], positive self-reflections are significant components of the self-efficacy theory [19]. Here are some student comments: "*That was such a good course offered. It was amazing," "I loved getting hands on experience programming VR applications and doing the project as an individual, not in a group,"* and *"I liked the integration of VR and mechatronics and how we can combine the two to create applications that can help in that regard."* Question 8 was assessing the challenges students had in the course. Students did not have any problems with the VR concepts, only the implementation. Most comments addressing challenges were dealing with the EON Professional IDE. For course improvements (Question 9), the students attending the course during the first year suggested developing a good tutorial on 3ds Max. Based on this feedback, a short tutorial was provided to the students enrolled in the VR course the second year. The students from the second year suggested "more scripting earlier" and creating JavaScript tutorials and exercises since they realized that this was a more powerful programming tool than the EON's graphical editor. Question 10, "Any other thoughts?" prompted a few interesting comments dealing with EON Professional's more sophisticated functions, other VR devices like Oculus Rift, Vive, Kinect, etc., as well as expanding the course to implement one of the game development software suites such as Unity or Unreal Engine.

During informal interviews with students, most of them expressed the desire to continue working with the CAVE to improve their existing VR projects and to become more proficient with EON Professional. Some of the students proposed to implement VR devices not introduced in the labs. Since user tracking in VR was not well emphasized in the class, one student volunteered to develop a set of examples for the Vicon IR cameras based on an example provided by EON Reality. The above facts indicate that students' motivation for working with VR increased.

Summary and Conclusions

A concise description of a first-year graduate level VR course using EON Professional and the CAVE VR environment is provided. Some examples of student work are disclosed. An assessment of student attitudes and perceptions towards the VR class and lab was performed through pointed questionnaires, informal individual interviews, and discussions. Students claimed that they learned much, liked and appreciated most of the labs, and were proud of their projects. They mildly disliked that there was only one copy of the EON Professional software so they had to schedule their time on the machine including using TeamViewer, that the instruction book/manual was not available (discontinued), and that the software changed so quickly that some of the features stopped working from one release to another. However, they were not annoyed by the fact that the computer could not support 3D viewing on the large screen and the computer monitor simultaneously. Overall, students' VR experiences were positive.

Bibliography

[1] W. R. Sherman and A. B. Craig, *Understanding Virtual Reality: Interface, Application, and Design* (The Morgan Kaufmann Series in Computer Graphics), Morgan Kaufmann 2003.

[2] G. C. Burdea and P. Coiffet, *Virtual Reality Technology, 2nd Edition*, John Wiley and Sons, 2003.

[3] Justice, Bergerud, Garrison, Cariero, and Churches, *Interactive 3D Application Development – Using EON Professional for Creating 3D Visualizations*, EON Reality Inc. and Kentucky Community and Technical College System, 2010.

[4] D. A. Kolb, *Experiential Learning: Experience as the Source of Learning and Development*, Prentice Hall, Englewood Cliffs, N.J., 1984.

[5] J. N. Harb, S. O. Durrant, and R. E. Terry, ”Use of the Kolb Learning Cycle and the 4MAT System in Engineering in Education,” *Journal of Engineering Education*, Vol. 82, April 1993, pp. 70-77.

[6] J. N.Harb, R. E. Terry, P. K. Hurt, and K. J. Williamson, *Teaching Through the Cycle: Application of Learning Style Theory to Engineering Education at Brigham Young University*, 2nd Edition, Brigham Young University Press, 1995.

[7] L. E. Ortiz and E. M. Bachofen, “An Experience in Teaching Structures in Aeronautical, Mechanical and Civil Engineering, Applying the Experimental Methodology,” *2001 American Society for Engineering Education Annual Conference & Exposition Proceedings*, Session 2526.

[8] M. Abdulwahed and Z. K. Nagy, Applying Kolb’s Experiential Learning Cycle for Laboratory Education, *Journal of Engineering Education*, July 2009, pp. 283-294.

[9] D. A. Wyrick and L. Hilsen, “Using Kolb’s Cycle to Round out Learning,” *2002 American Society for Engineering Education Annual Conference and Exposition Proceedings*, Montreal, Canada, June 17-19, 2002. Session 2739.

[10] T. S. Harding, H.-Y. Lai, B. L. Tuttle, and C. V. White, “Integrating Manufacturing, Design and Teamwork into a Materials and Processes Selection Course,” *2002 American Society for Engineering Education Annual Conference and Exposition Proceedings*, Montreal, Canada, June 17-19, 2002. Session 1526.

[11] H. A. El-Mounayri, C. Rogers, E. Fernandez, and J. C. Satterwhite, “Assessment of STEM e-Learning in an Immersive Virtual Reality (VR) Environment,”*2016 American Society for Engineering Education Annual Conference and Exposition Proceedings*, New Orleans, LA, June 26 – 29, 2016, Paper ID 15724

[12] Z. A. Syed, T. Wang, K. K. Frady, K. C. Madathil, J. Bertrand, R. S. Hartley, J. R. Wagner, and A. Gramopadhye, “Use of Virtual Reality Tools in an Undergraduate Mechanical Engineering Manufacturing Course,” *2017 American Society for Engineering Education Annual Conference and Exposition Proceedings*, Columbus, OH, June 25 – 28, 2017. Paper ID 17897

[13] X. Peng, B. Isaac, and R. T. Wilkins, “Development of Nanoscale Virtual Reality Simulations for the Teaching of Nanotechnology,”*2012 American Society for Engineering Education Annual Conference and Exposition Proceedings*, San Antonio, TX, June 10 – 13, 2012. AC 2012-3817

[14] S. K. Chaturvedi, J. Yoon, and R. McKenzie, “Implementation and Assessment of a Virtual Reality Experiment in the Undergraduate Thermo-Fluids Laboratory,” *2012 American Society for Engineering Education Annual Conference and Exposition Proceedings*, San Antonio, TX, June 10 – 13, 2012. AC 2012-3412

[15] P. Ari-Gur, P. Ikonomov, R. Rabiej, P. Thannhauser, M. M. Hassan, D. M. Litynski, and R. Schwartz, “Transforming Undergraduate Engineering Education with 3D Virtual Reality Laboratory,” *2013 American Society for Engineering Education Annual Conference and Exposition Proceedings*, Atlanta, GA, June 23 – 26, 2013. Paper ID 5826

[16] K. C. Madathil, K. Frady, R. Hartley, J. Bertrand, M. Alfred, and A. Gramopadhye, “An Empirical Study Investigating the Effectiveness of Integrating Virtual Reality-based Case Studies into an Online Asynchronous Learning Environment,” *Computers in Education Journal*, V 8, Issue 3, pp. 1-10, Sept. 2017.

[17] Y. Tang, S. Shetty, and X. Chen, “Educational Effectiveness of Virtual Reality Games Promoting Metacognition and Problem-Solving,” *2012 American Society for Engineering Education Annual Conference and Exposition Proceedings*, San Antonio, TX, June 10 – 13, 2012. AC 2012-3380

[18] C. Nippert, and B-H. Um, “Comparison of Learning Between Experiments using Virtual Reality and Hands on Experiments What is Real Enough?,”*2011 American Society for Engineering Education Annual Conference and Exposition Proceedings*, Vancouver, Canada, June 26 – 29, 2011. AC 2100-162

[19] A. Bandura, *Self-Efficacy: The Exercise of Control*, W. H. Freeman and Company, NY, 1997.

APPENDIX – Samples of Student Work: Storyboards and VR Projects

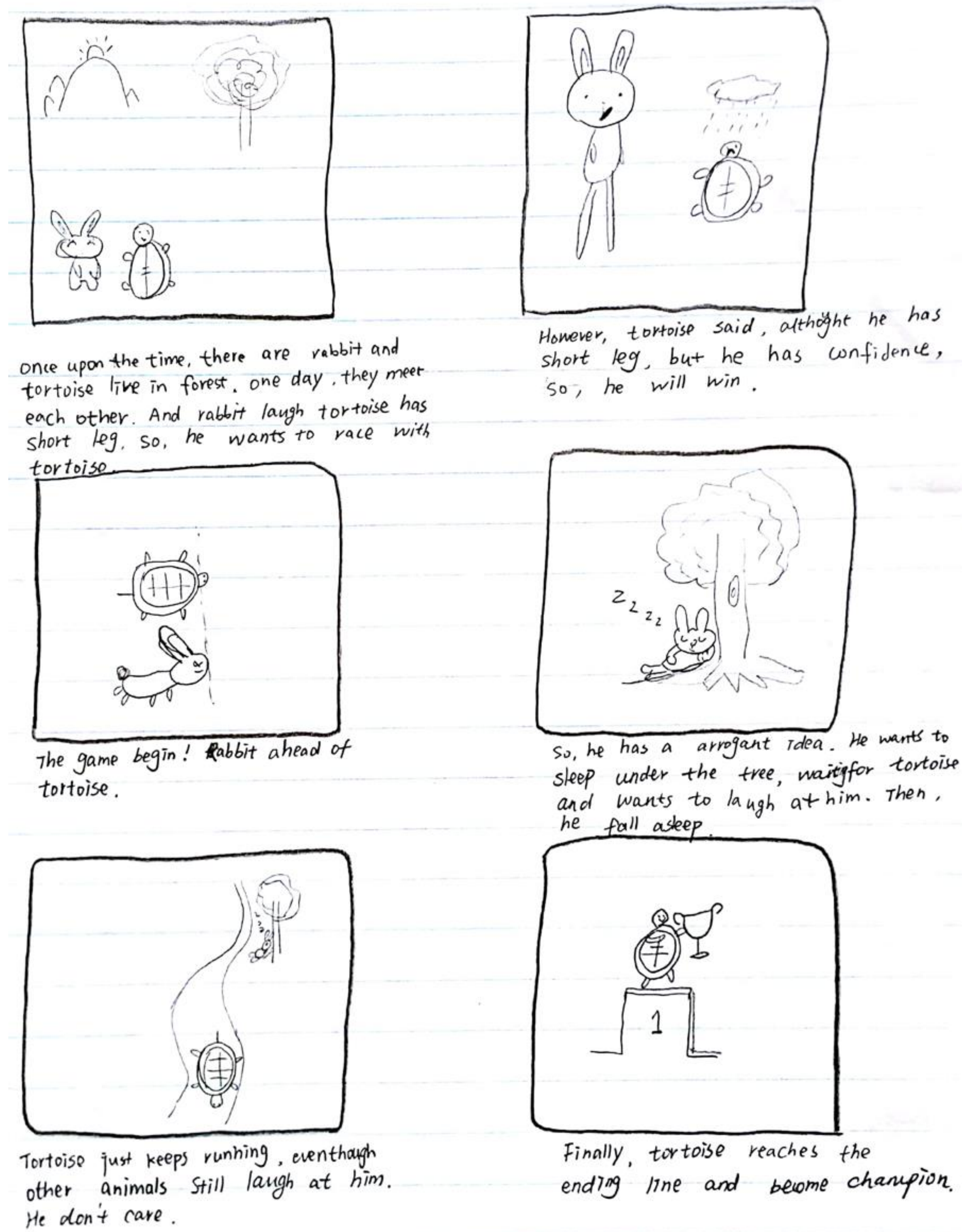


Figure A1. Storyboard: The Tortoise and the Hare

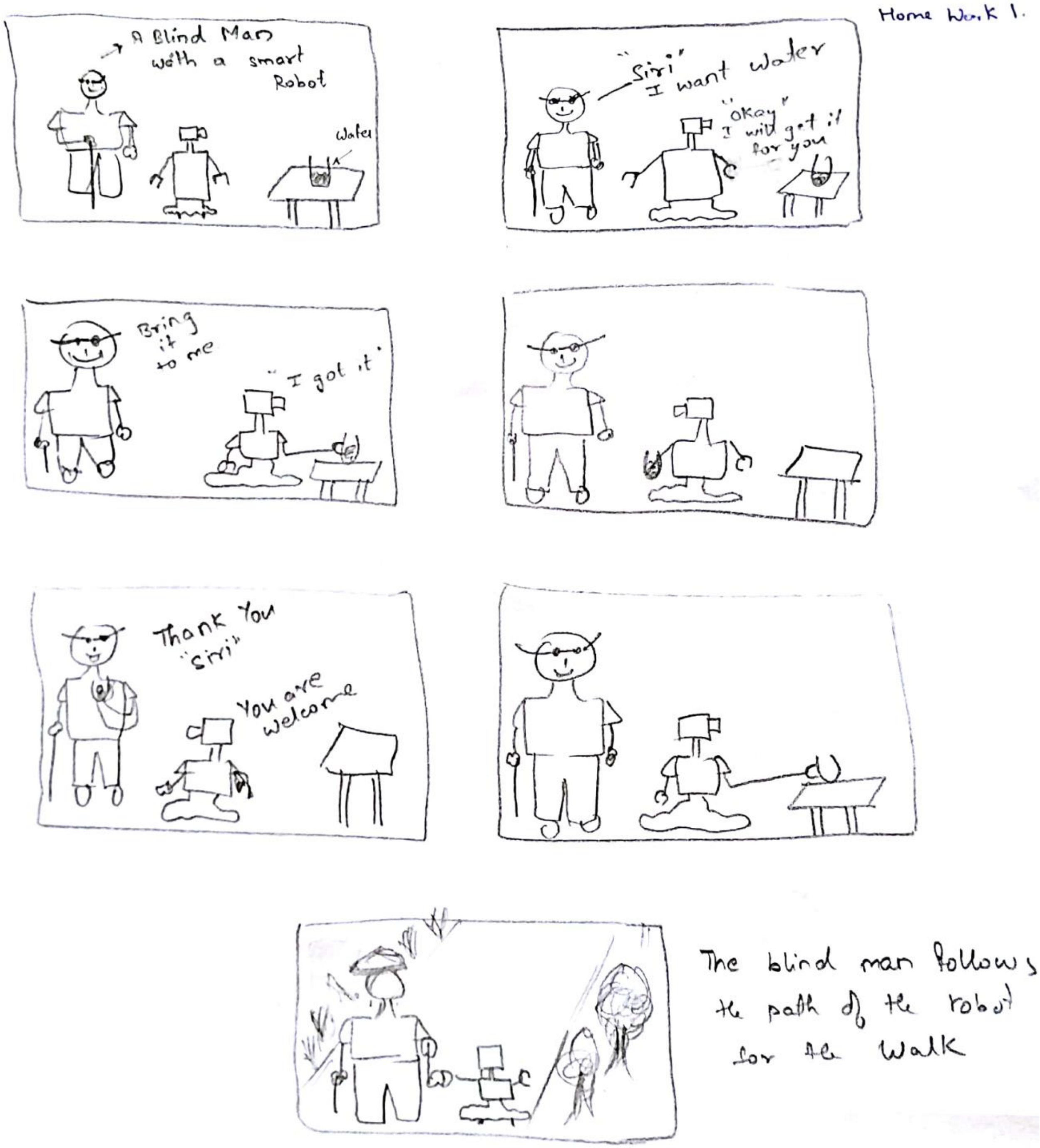


Figure A2. Storyboard: Robot and I

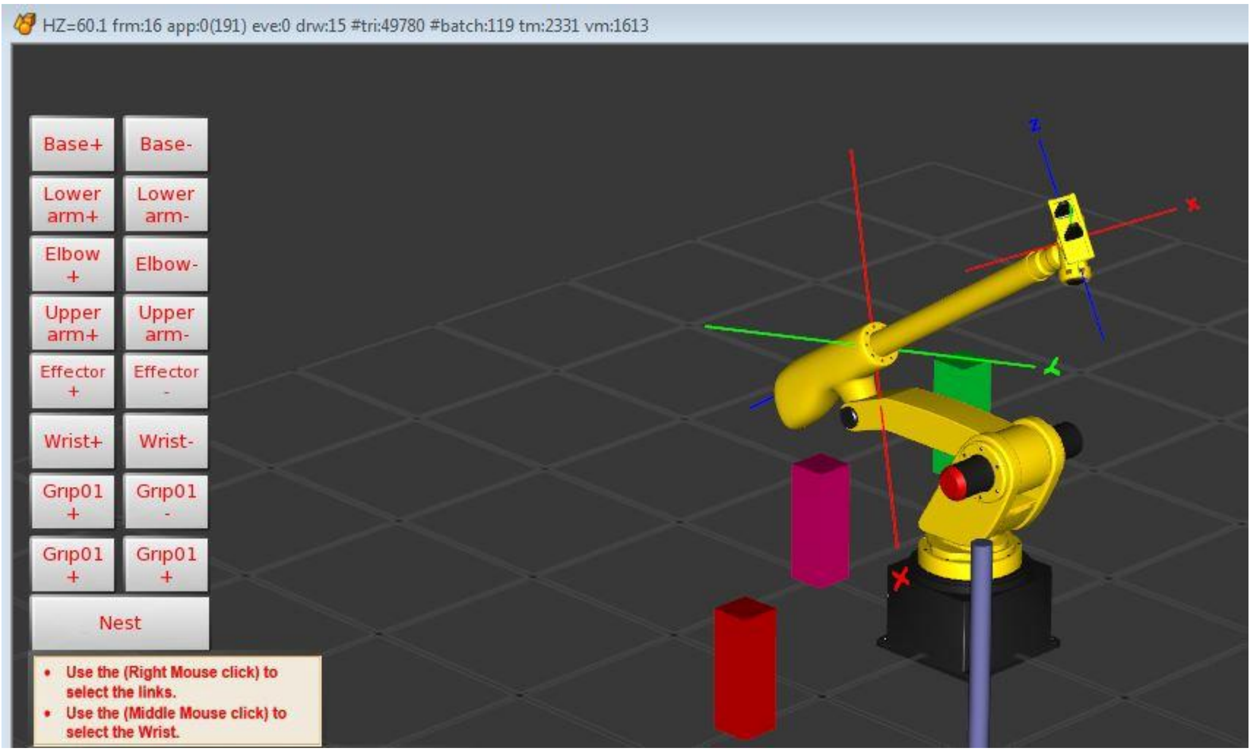


Figure A3. Snapshot of a VR Project: Virtual Robot Controls

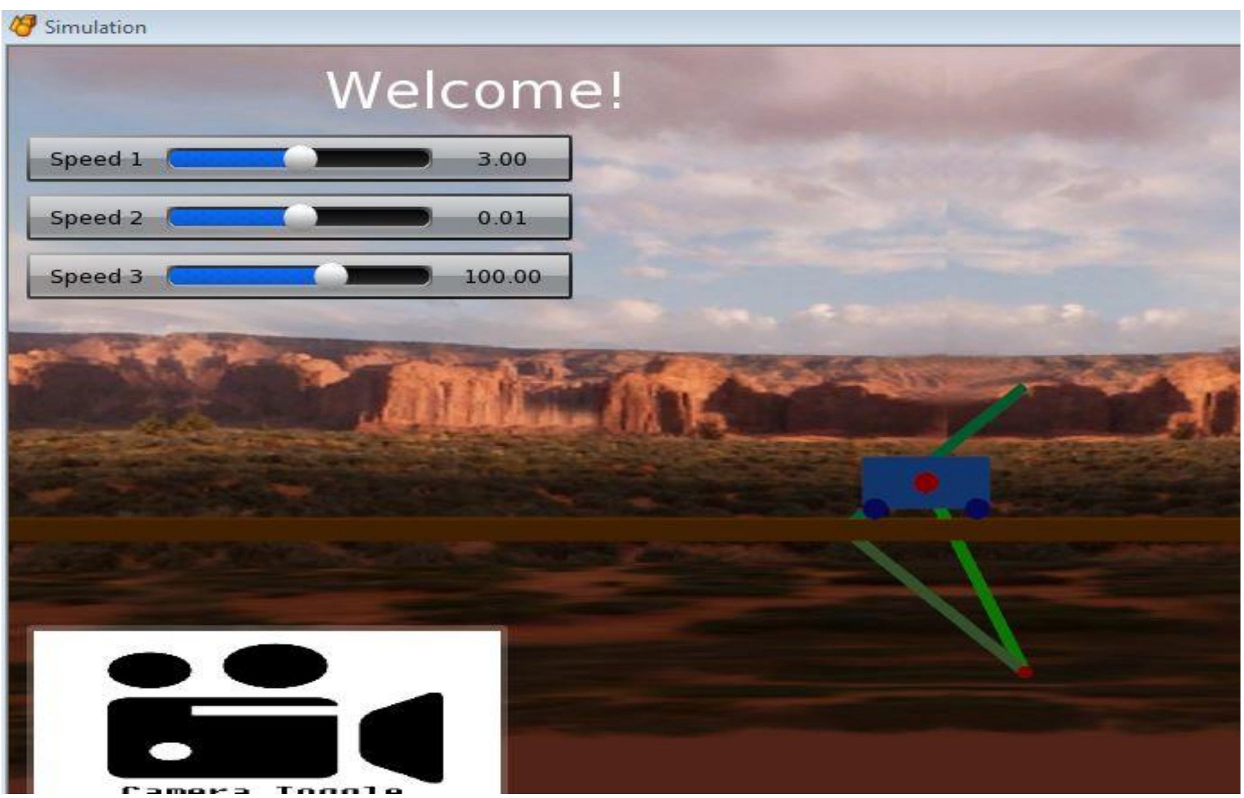


Figure A4. Snapshot of a VR Project: Three-link Inverted Pendulum Control