AN IVR ENGINEERING EDUCATION LABORATORY ACCOMMODATING CDIO STANDARDS

Jörg Schminder, Filip Nilsson, Paulina Lundberg, Nghiem-Anh Nguyen, Christoffer Hag, Hossein Nadali Najafabadi

Department of Management and Engineering, Linköping University

ABSTRACT

This paper presents the development of an educational immersive virtual reality (IVR) program considering both technological and pedagogical affordances of such learning environments. The CDIO Standards have been used as guidelines to ensure desirable outcomes of IVR for an engineering course. A learning model has been followed to use VR characteristics and learning affordances in teaching basic principles. Different game modes, considered as learning activities, are incorporated to benefit from experiential and spatial knowledge representation and to create a learning experience that fulfils intended learning outcomes (ILOs) (defined by CDIO Standard 2 and Bloom's learning taxonomy) associated with the particular course moment. The evaluation of IVR laboratory highlights the effectiveness of the approach in achieving ILOs provided that pedagogical models have been followed to create powerful modes of learning.

KEYWORDS

Immersive Virtual Reality, Virtual Learning Environment, Standards 2, 6, 8 and 11.

INTRODUCTION

Active teaching forms where the most perceptive channels (sight, hearing, smelling, etc.) are involved and attention to different information sources can alter freely, are often preferred by students. One active teaching approach that has been considered as an important element of universities curricular since the early stages of development is laboratory work. This activity educates scientists and engineers through practices of theories and knowledge in various ways. Nowadays many experimental based labs are being replaced by computer-based labs and the trend is growing rapidly. This is primarily due to that computer-based labs not only offer practices of knowledge and theories but also give another level of experimentation including improved visualization, sense of presence, no time and space limit, and risk-free experiments for certain disciplines such as aerospace and medicine. In this era, a technology, which has grown in importance over the last decade, is virtual reality (VR) (Gartner, Inc., 2017; The Goldman Sachs Group, Inc., 2016). While the technic was originally developed for the computer game market, it started to build appeal for the educational sector, which is together with the healthcare sector already today the third largest customer group of VR tools (Karl, et al., 2018). Like other forms of teaching, the use of VR for educational purposes in courses and programs demands pedagogics considerations such as a specification of learning objectives, alignment to course intended learning outcomes and assessment. This paper reports the development of an educational VR program in an engineering course and highlights the pedagogical considerations including the use of CDIO Standards as guidelines. The VR program was developed for an introductory course in *Gas Turbine Engines*, offered on the master level at Linköping University.

BACKGROUND

Virtual reality as an educational tool

A lab activity offers a learning environment that students can either apply already gained theoretical knowledge on a practical problem (giving learned knowledge a meaning), and/or to discover new facts, concepts, and principles for themselves. In such a case the teachers and lab assistants role is to guide students towards achieving certain goals. Laboratories or supervised practise including VR plays an important role in educational programs within engineering, medicine, or social science. Freina and Ott (2015) name four motivations for the use of VR in education: "time problems", "physical inaccessibility", "limits due to a dangerous situation" and "ethic problems". In addition, acquiring and operating instructional laboratories are today often connected to heavy costs. However, they all boil down to the same basic idea, namely that VR makes it possible to experience and learn from situations that in one way or another cannot be easily accessed physically (Freina & Ott, 2015). These motivations rely on characteristics of this technology, which according to Sherman and Craig (2003) consists of four key elements: a virtual world, immersion, sensory feedback and interactivity. The use of lab as a constructivist educational approach in virtual worlds creates a learning environment which is capable of responding and interacting with students' movements and inputs which allows them to experience a mediated sense of presence (Chien, You-Send, & Hsieh-Lung, 1997). This is referred to as virtual learning environment (VLE).

VLEs can be experienced by applying different information and communication technologies (ICT). The visual immersion and situation awareness inside a virtual environment is commonly experienced through a computer screen which simply can be desktop based (desktop virtual reality) or, when using more sophisticated equipment for immersive 3D experiences, a cave automatic virtual environment (CAVE) alternatively a head-mounted display (HMD) based system (Freina & Ott, 2015). By applying a position tracking system, which translates in real time the student's physical position and movements into direct feedback inside the VR, it is possible to interact, change the field of view (FOV) or walk around within the virtual world.

The hardware's quality, ergonomics and intuitive design play an essential role in providing a high level of sensory feedback and interactivity which in turn forms a main fundament for a high immersivity. Dalgarno and Lee (2010) point in the same direction identifying the representation fidelity and the learner interaction as the biggest factor that will contribute to a higher degree of immersion.

The terminology "immersion" can be simplified explained as the feeling of self-location within the virtual environment (Lau & Lee, 2015). Freina and Ott (2015) note that the term immersion is often being used in the meaning of "spatial immersion", as in the perception of being physically present in the virtual world. Slater (2003) stresses in his study that immersion is not the same as "presence" and that these terms should be kept separate. Immersion, Slater

(2003) argues, is an objective term for the way the virtual world is presented to the user, as in the number of different sensory displays or the simulations' fidelity to the user's movements, whereas presence is the user's perception of the immersion. Shortly, the feeling of presence is a human reaction to immersion. Moreover, apart from the already mentioned *sensory immersion,* which is best experienced by help of HMDs, other immersive aspects (Dede, 2009) like *actional immersion,* referring to be immersed in the task, *narrative immersion,* as induced by intoxicating real or fictional stories, and *social immersion* (Krämer, 2017)*,* considering social aspects between the students or the students and the teacher, are important when aiming for a high learning outcome. Fowler (2014) follows Salter's definition of immersion and presence and draws the conclusion that immersion provides a bridging concept between the technological, psychological and pedagogical experience of learning in three-dimensional virtual environments. This makes immersion an important factor to take into consideration whenever choosing or designing VLEs.

Educational VR challenges and methods of resolution

Of all the research and work done in the field of VR related VLE's there seems to be a shortage of papers that have had a clear pedagogical underpinning (Fowler, 2014; Mikropoulos & Natsis, 2011). According to a review of educational virtual environment design studies by Mikropoulos and Natsis (2011), few of the examined studies had a clear pedagogical foundation to motivate VLE design decisions. Although studies have suggested learning models that integrate the characteristics of virtual learning environment to their learning affordance (see Dalgarno & Lee, 2010), it is apparent that even such models miss the pedagogical aspects such as intended learning outcomes (ILO) and objectives. However, even if it does not exist yet one model that includes all pedagogical frameworks or taxonomy for VR related VLEs, it is possible to find models that can help to analyse the suitability of an ICT, to integrate pedagogics during a VLE design, and to evaluate a VR based learning activity.

Pantelidis (2009) and Fowler (2014) suggest frameworks for developers of VLEs, which considers both technical as well as pedagogical aspects. Pantelidis (2009) model recommends in ten steps how to approach, evaluate and develop a VLE. The model requests considerations of the VLE's learning objectives, the advantages of using VR to reach a specified learning goal, the right VR equipment/environment, and suggesting a VLE development cycle. Fowler (2014) presents a Design for Learning (DfL) approach, which combines Dalgarno and Lee (2010) model for developing three-dimensional VLEs with Mayes and Fowler (1999) concept of pedagogical immersion. The DfL framework provides three VLE design requirements: "learning stages", "learning objectives" and "learning activities". By basing the design approach on Fowler and Mayes (1999) three learning stages (1) conceptualization, (2) construction and (3) dialogue, learning objectives (or outcomes) can be determined, such as "exposing learners to new concepts, theories and facts" (conceptualisation), or "reflecting critically" (dialogue). To reach these learning objectives different learning activities must be defined and carried out, for example, "receiving information" or "self-assessment of level of competence". Depending on the case, the practitioner then has to determine which approach will be chosen to reach the specific requirements. The whole design process can be documented in a learning specification, for example in the form of a storyboard, a table or a formal learning specification (Fowler, 2014).

Designers of a VLE can also get guidance from the game industry and related research. This counts in special for educational games. Erhel and Jamet (2015) define digital game-based learning (DGBL) as an activity where the player receives educational goals through an educational computer game (ECG). The learning benefits of digital games to nongame conditions and the influence of simulations and virtual environment on a higher cognitive level have been addressed among others by Clark, Tanner-Smith and Killingsworth (2016), and Merchant, Goetz, Cifuentes, Keeney-Kennicutt and Davis (2014).

Designers should also be aware of the psychological limitations of the student. It exists a risk that the amount of visual information in VLEs easily overshoot the perceptivity of the student and by that learning decrease. To avoid this risk, the cognitive load theory (CLT) with its universal set of principles for managing cognitive loads and ensuring efficient learning, can be consulted. Based on the theory it is important to decrease the student's extraneous cognitive loads often introduced due to unnecessary audio or visual stimulation (Liu, Bhagat, Gao, Chang, & Huang, 2017).

REALISATION

Development of an IVR laboratory for an engineering course

The VR based laboratory, subject of this study, is part of an introductory course for gas turbine engineering (TMMV12) at Linköping University which inheres a number of teaching and learning activities including lectures, labs, assignments and self-study. The objective of the course is to teach students, within a 160 hours of total study time (6 ECTS credits), the fundamentals of gas turbine and jet engine performance, deeper their understanding of the different sub-components functionality, and discuss different design problems from a fundamental thermodynamic, fluid mechanic and aerodynamic perspective.

As part of the educational digitalization process, ongoing at Linköping University, and a feasibility study of Smart Pedagogy (assessment of the pedagogical and technological affordances of different ICT approaches, see (Daniela, 2019, Pantelidis, 2009)), VR deemed to be a beneficial digital learning tool for the above-mentioned course. Therefore, four HTC Vive systems with a resolution of 1080 x 1200 pixels per eye and a 110-degree field of view were acquired. The used computers had an Intel® Xenon® CPU E5-1650 V3, 32 GB RAM and a NVIDIA® GeForce® GTX 970 graphic card. The laboratory was performed in an educational VR arcade (Figure 2(b)), newly established at Linköping University, with four independent working spaces separated by lightproof curtains. This allows four students to join the laboratory at the same time conducting the lab after a short introduction to the VR equipment. Each individual can finalize the task independently within approximately 30 min. While the students are in the VR, a lab assistant monitored the students' progress from the outside following their actions on the desktop screens and provided pedagogical and technical help if necessary.

The VR lab intended learning outcomes are based on Blooms Taxonomy (Bloom, Engelhart, Furst, Hill, & Krathwohl, 1956) and CDIO Standard 2 focusing in general on individual experimentation as well as knowledge discovery by applying engineering reasoning, system thinking and problem-solving. In more detail, ILOs were defined as to identify the type of engine and its different parts, to understand the operating phases of a gas turbine, to list different thermodynamics station and numbering procedure, and to reflect about advantages and disadvantages of the given engine's design. Then, the laboratories ILOs were translated into specific tasks formulated as questions. In addition, the students' preferred learning styles and needs including learners attributes (age, origin, academic year, etc.), prerequisite requirements (both course content knowledge and VR related) preferences (reading, instructions, group work, analog/digital, etc.) and motivations (grades, knowledge gain, play, etc.) have been analysed. Subsequently, it was looked after already available VR application, which could suite the laboratory ILOs as well as student needs and provide sufficient pedagogic to the same time. Due to the lack of VR applications that fulfil the current specific course requirements as well as pedagogical needs, it has been developed internally.

The conceptual design of the app development started with an ideation phase including a brainstorming, which resulted in a suitable basic program layout including three learning modes: 1. Lab Mode, 2. Examination Mode, and 3. Exploration Mode. In the next step was the previous specified ILOs translated into VR learning activities by utilizing Fowlers (2014) DfL approach. Since the application should have characteristics of an ECG, relevant aspects of the DGBL approach were extracted from the literature and drawn into a list of “must”, “should” and “could”. That list was further developed into a table with a list of goals and later broken down into different ECG design and implementation requirements. The basic concept was subsequently compared with the CDIO Syllabus 2.0 (CDIO, 2019), and if necessary, completed, in order to ensure that the basics of Standard 2, 6, 8, and 11 were from the beginning included in the ECG design.

In the concept realization phase, the abovementioned modes were defined. After ordering exercises and tasks, flowcharts for different lessons were created. These flowcharts lay the foundation for the storyboards, which specified in greater detail the user interaction with the program, as well as the most basic environmental setups. The main model of the application, the DGEN 380 turbofan jet engine developed by Price Induction, was directly imported in Unreal Engine 4 as 3D computer-aided design (CAD) object. The company provided original CAD model however was too rich in details and had to be decreased in its complexity such that it fits the pedagogical needs of the VR laboratory.

From the beginning of the conceptual phase until the introduction of the application in the classroom, the programs were iteratively testified to improve the learning modes pedagogics and didactics by resolving the technological design and functional issues.

Classroom experiences applying an IVR laboratory

The current beta version of the developed educational VR application has three modes (Figure 1): 1. Lab Mode, 2. Exploration Mode and 3. Examination Mode, which enables the use of different pedagogical approaches. The Lab Mode is designed with clear instructions and tasks to develop students’ knowledge step by step. The Exploration Mode offers a more open learning approach where the student can freely discover different aspects of the jet engine design. These two modes use feedback and flexible experimentation for learning that was positively commented during the development phase; students’ statement: “liked the lab mode, but especially the exploration mode”. While the later mode may have pedagogical benefits, the lab mode is more efficient from time management on finalizing a particular task following some instructions, about 30 min to finish. Both modes aim to engage students’ active learning (CDIO Standard 8) and promote hands-on learning by placing them virtually in a realistic engineering environment (CDIO Standard 6) in which a complex mechanical system, here a jet engine, can be analysed and manipulated. In accordance with CDIO Standard 11, the Examination Mode seeks an individual knowledge level and task completion through an assessment and provides feedback to both teacher and students with students’ pre- and post-laboratory knowledge, which is valuable due to uneven knowledge background. Moreover, such information can also be inputs for further task development, the level of complexity or, in terms of ECG, creation of more challenging games.

The right sensory design is of high importance for the learning outcome and degree of immersion, see (Saleeb & Dafoulas, 2011), which has been reflected through the design of different environments. The lab environment (Figure 2 (a)) relates strongly in form and colour to the architectural design of the university (Figure 2 (b)), known for students, to decrease the risk of mental overload. This will prevent experiencing a new environment by the students and helps in focusing on learning. For the Exploration Mode (Figure 2 (c) and (d)), the students were placed inside an aircraft workshop/hangar. The idea is that they can go around, see the engine in both aircraft installed and uninstalled conditions and explore parts and functions in their "natural" context. The students who used the scenery were all positive about the hangar environment expressing it was "cool" and "impressive".

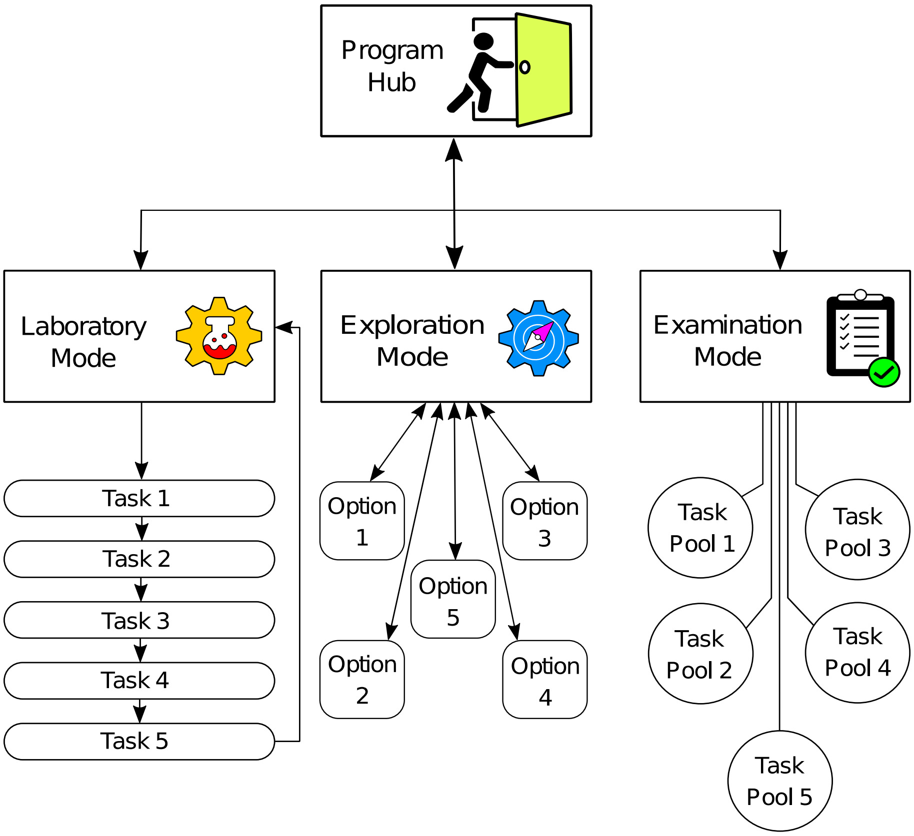


Figure 1. Program structure of the VR laboratory application. The Laboratory Mode includes different tasks, which are solved one after another. The Exploration Mode offers different task options from which the student can choose. The Examination mode provides task pools for individual student knowledge assessment.

Cognitive overload in the lab mode was also prevented by introducing the jet engine parts first as simple labels and later systematically by a realistic presentation of the object. In the actual version of the application, engine parts have different colours aiming to support the student indirectly with information about which parts are related to each other. Although a more realistic material representation could be beneficial (commented also by students), the degree in which this should be implemented is correlated to defined ILOs and human's perceptual abilities. For instance, due to human's visual perception limitations, rotations of certain engine parts, like the fan, were significantly reduced so the students can reflect on movements of components, direction, etc.

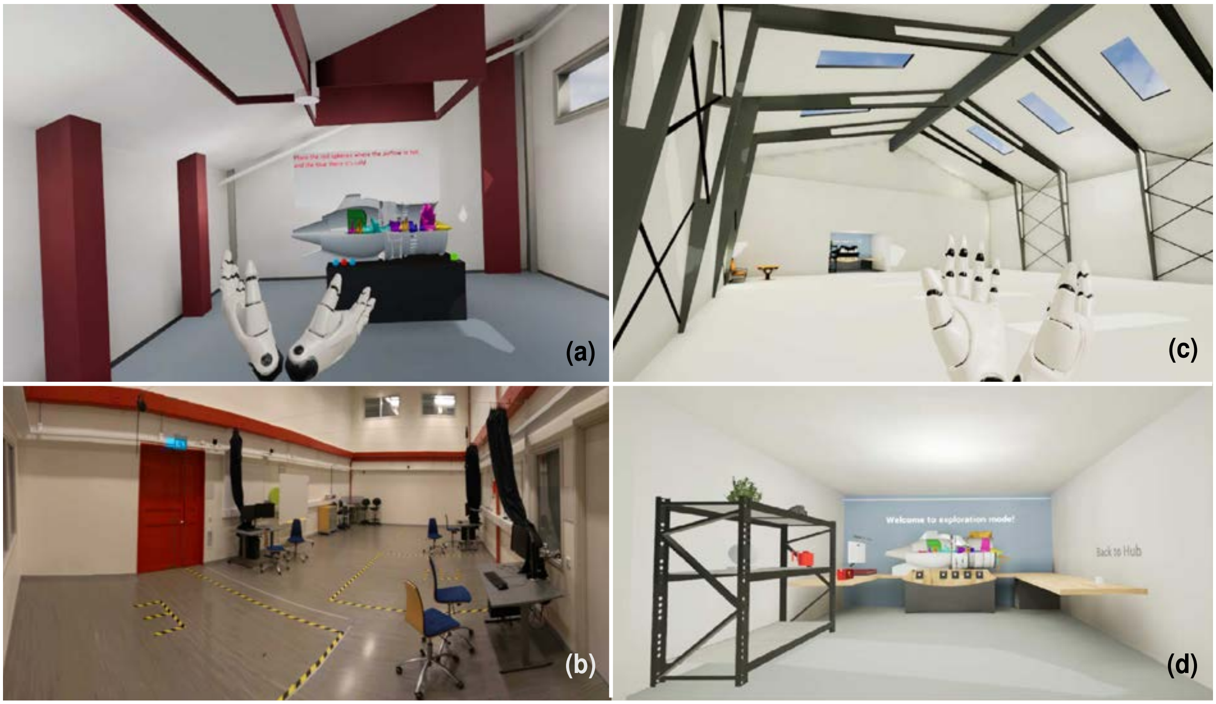


Figure 2. To minimize cognitive overload and hold student focused the VLE of the Laboratory Mode (a) equals the design of the universities architecture (b). In contrast, the Exploration Mode VLE is a more context related environment placing the students in an aircraft hangar (c) with integrated jet engine workshop (d).

Another example was related to readability of text and instructions where students experienced some level of difficulties due to the blurry or fast movement of text. The first issue, blurry text, is probably related to technological limitations such as the relatively low resolution of the VR goggles. When using the glasses intensively, longer time intervals, the readability was sometimes decreased by slightly fogged lances, caused by human perspirations. To overcome the problem of readability text size and contrast was increased as well as functions for self-determined text speed and to read-out are planned for the next update. The recently tested HTC Vive Pro system also shows improvements in readability due to the enhanced resolution.

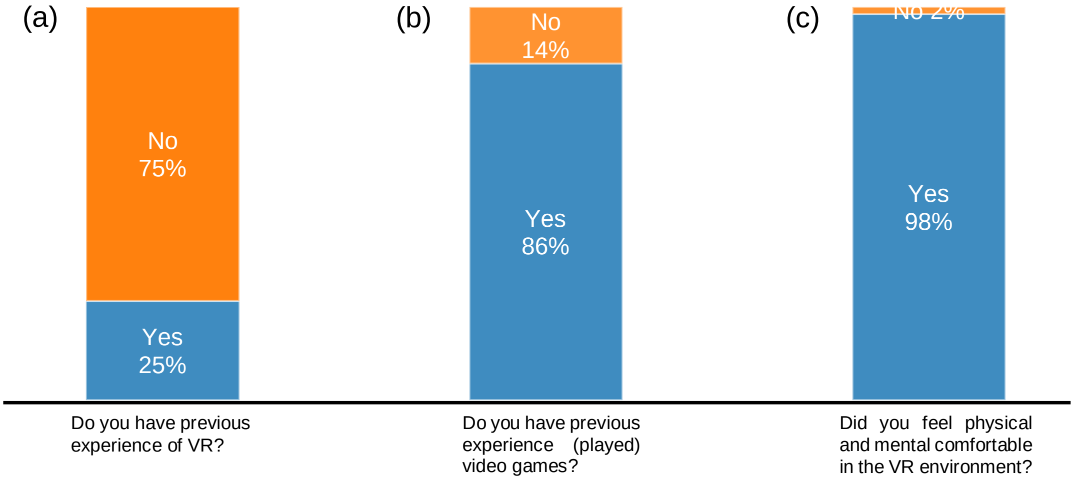


Figure 3. Students' response regarding to VR experience, video games and comfort in VR environment.

In a survey, conducted directly after the VR lab, 98% of the 110 students, which so far joined the IVR laboratory, responded that they felt physical and mentally comfortable in the VR environment (Figure 3 (c)). Problems reported in other papers (Davis, Nesbitt, & Nalivaiko, 2014) related to "cybersickness" causing dizziness of the user were not expired by the students. However, this is most likely since students in this VLE did not experience any fast-visual changes, which could affect their balance system negative. The positive mental comfort is also reflected in the question: Could you focus on the learning task or did you experience any disturbances? 86% of the students reported no problems (Figure 4 (b)), most likely due to sensory design consideration, 13% had some difficulties to focus, while only 1% could not focus at all. The named reasons for the students' difficulties reach from already mentioned readability problems, over unclear task formulation and small disturbing bugs in the program, to issues with the hardware (loose HMD or confusion with the controllers' button functions). In answer to the question of how intuitive it was to work in the virtual reality lab (Figure 4 (a)), 41% of the students reported no problems at all while 55% indicated minor difficulties and 4% more severe problems. One of the major issues mentioned by the students, also observed by the teacher, was to teleport within the VLE to reach objects, which were outside the area where the student could physically reach them.

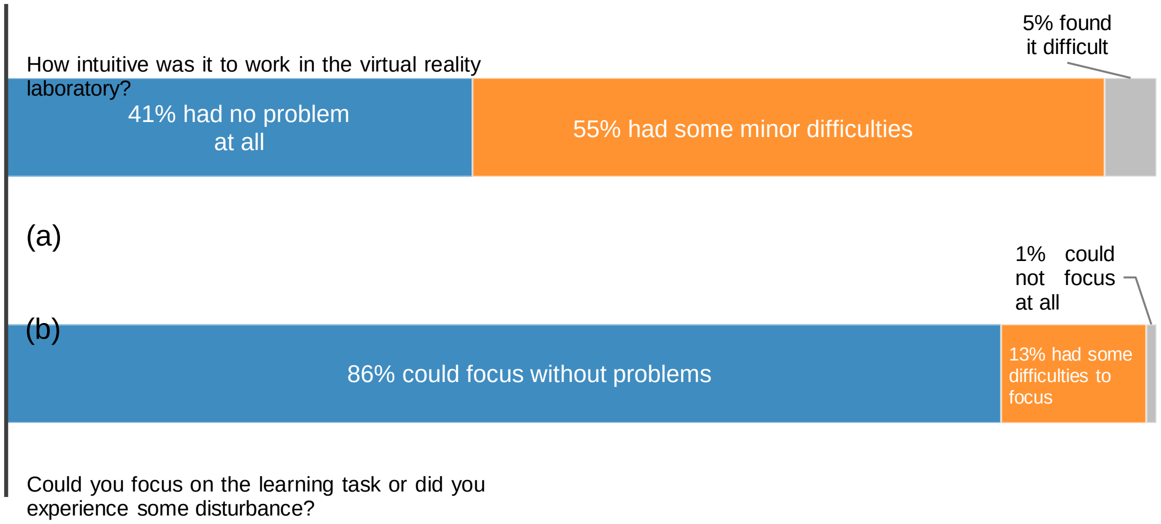
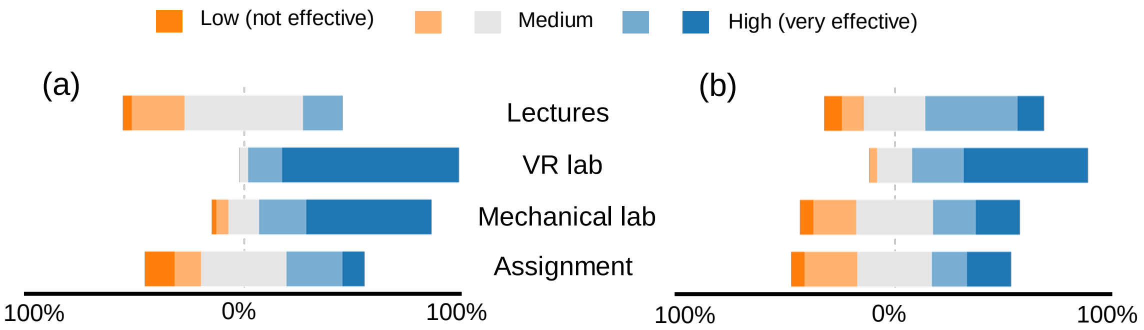


Figure 4. The intuitiveness of the VR program and sensory design effect on focus in actual learning has been positively commented.

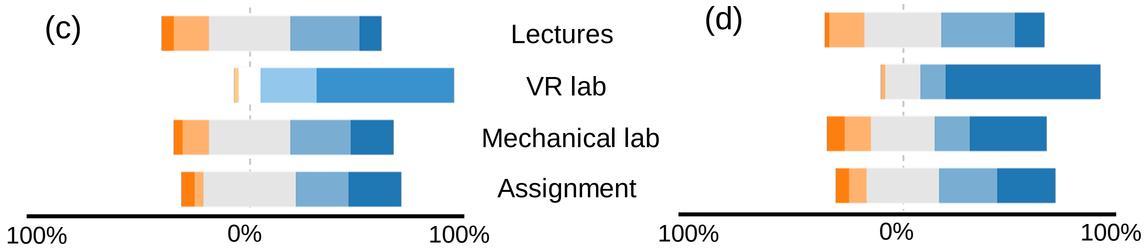
Moving through the VLE by teleporting needs synchronously coordination of the VR nonvisible controller buttons and relocation of the VLE's internal virtual operational area. A possible solution for the future could be to present the controllers inside the VLE as how they look in real instead of illustrating them as hands by simultaneous simplification of the teleportation function. However, despite the high number of students who never experienced IVR before coming to the lab, 75% (Figure 3 (a)), and some minor problems was the overall feedback positive. A student summarized this with: "… I think the present issues in the VLE did not really disturbed the learning. I think I will remember more from what was thought because of the unusual teaching tool and method." The teacher observed also that students who indicated (Figure 3 (b)) no previous video game experience in the survey (14%) struggled more with the controllers, were less agile in their movements, and tried less thing out in the VLE, than students who played videogames before.

To evaluate the achievement of VR specific ILOs and students’ perception of these ILOs, an additional survey was conducted at the end of the course. The students had to relate different ILOs to four learning activities included in the course. Note that the survey contains ILOs that were not intended particularly for VR lab to evaluate students’ attention on designed activities for specific ILOs, (see categories (e) and (f) in Figure 5). The results show clearly students’ appreciation in the contribution of VR lab to achieve ILOs (a)-to-(d) (highest contribution from VR). It is also evident from the figure that ILOs (e) and (f) have nearly zero contribution from the VR lab, as anticipated (not intended for VR lab). For all the presented ILOs, the percentage response rate of High (very effective) or Low (not effective) is quite significant when it comes to VR, i.e. lower variability in response for VR compared to other activities. An interesting observation is also that the mechanical lab in which students had the possibility to observe a real gas turbine is still after VR lab in facilitating students to achieve these ILOs.



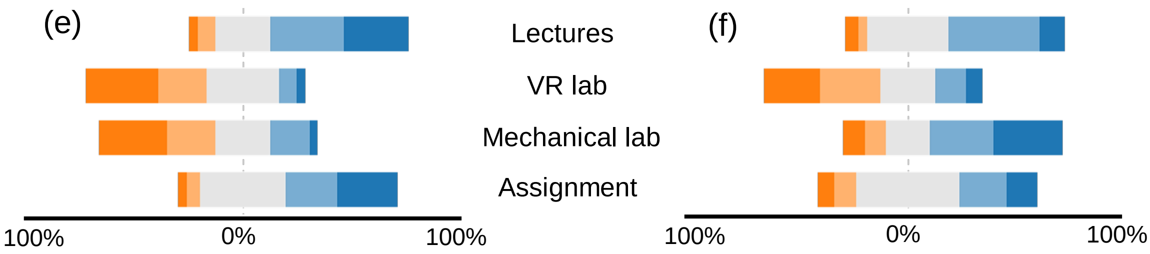
Rank for each activity when it comes to identifying basic GT components including Lubrication & Bearing!

Rank for each activity when it comes to identifying GT station numbering!



Rank for each activity when it comes to distinguish between hot and cold flow direction!

Rank for each activity when it comes to categorize High/Low pressure part!



Rank for each activity when it comes to define ideal/real GT thermal cycle!

Rank for each activity when it comes to discuss compressor design and stability!

Figure 5. The results of survey with response rate of 61% (51 answers out of 84) about students’ perception on achieving different ILOs through different activities. ILOs (a)-to-(d) were intended to be persuaded through VR lab, whereas categories (e) and (f) were intended for assignment and relavant lectures.

Even if the presented application is still a beta version and further improvements are necessary, both surveys and the students' feedback indicate satisfactory achievements using the chosen method to develop a VR laboratory from a technical and pedagogical point of view. Placing the students learning, the physical and psychological needs and limitations, as well as motivation in the canter of the VR application development process provides from the beginning a good foundation for achieving ILOs. Thereby, the frameworks presented in the literature can provide good guidelines for the development of a VR based laboratory even if some frameworks are from a practical standpoint too theoretical and/or too general.

CONCLUSION

A VR-based laboratory used in an engineering program, the basics in gas turbine has been developed considering the joint benefits of IVR technology and pedagogical frameworks to achieve specific ILOs. Earlier studies and experiences from this work show that IVR not only offers an affordable possibility to create and operate an instructive laboratory, but also it provides a supportive tool for active learning (which improve students' practical skills, a real-world context experience and a complex system learning through engagement). In addition, a pedagogic supported IVR laboratory covers CDIO Standards such as Standard 2, 6, 8, and 11. Concurrently, the standards also can provide a theoretical base for the design of an IVR laboratory. Summing up, an IVR based laboratory has a high potential to be a game changer in the university's practical education if, and only if, modern pedagogy and didactics are from the beginning considered and implemented. Technologies as IVR can only support a teacher not replace him.

REFERENCES

Bloom, B., Engelhart, M., Furst, E., Hill, W., & Krathwohl, D. (1956). Taxonomy of Educational Objectives. London: Longmans, Green and Co LTD.

CDIO, I. (2019, January 29). CDIO. Retrieved from CDIO Syllabus 2.0: http://www.cdio.org/benefits-cdio/cdio-syllabus/cdio-syllabus-topical-form

Chien, C., You-Send, Y., & Hsieh-Lung, H. (1997). Construction of a Virtual Reality Learning Environment for Teaching Structural Analysis. *Computer Applications in Engineering Education, 5(4).*

Clark, D., Tanner-Smith, E., & Killingsworth, S. (2016). Digital Games, Design, and Learning: A Systematic Review and Meta-Analysis. *Review of Educational Research, 86(1),* 79-122. doi:10.3102/0034654315582065

Dalgarno, B., & Lee, M. J. (2010, January). What are the learning affordances of 3-D virtual environments? *British Journal of Educational Technology, 41(1),* 10-32.

Daniela, L. (2019). Smart Pedagogy for Technology-Enhanced Learning. In L. Daniela, *Didactics of Smart Pedagogy (pp. 3-21).* Riga: Springer.

Davis, S., Nesbitt, K., & Nalivaiko, E. (2014). A Systematic Review of Cybersickness. *Conference on Interactive Entertainment* (pp. 1-9). Newcastle: ACM. doi:http://dx.doi.org/10.1145/2677758.2677780

Dede, C. (2009). Introduction to Virtual Reality in Education. *Themes in Science and Technology Education, 2,* 7-9.

Erhel, S., & Jamet, E. (2015, May 15). The effects of goal-oriented instructions in digital game-based learning. *Interactive Learning Environments, 24(8),* 1744-1757. doi: https://doi.org/10.1080/10494820.2015.1041409

Fowler, & Mayes. (1999). Learning relationships from theory to design. *ALT-J Research in Learning Technology, 7(3),* 6-16. doi:https://doi.org/10.1080/0968776990070302

Fowler, C. (2014). Virtual reality and learning: Where is the pedagogy? *British Journal of Education Technology, 46(2),* 412-422. doi:https://doi.org/10.1111/bjet.12135

Freina, L., & Ott, M. (2015). A Literature Review on Immersive Virtual Reality in Education : State of the Art and Perspectives. *Genova: Institute for Educational Technology, CNR*.

Gartner, Inc. (2017, August 15). Top Trends in the Gartner Hype Cycle for Emerging Technologies, 2017. *Retrieved from Smart with Gartner:* https://www.gartner.com/smarterwithgartner/top-trends-in-the-gartner-hype-cycle-for-emerging-technologies-2017/

Karl, D., Soderquist, K., Grant, A., Farhi, M., Krohn, D. P., Murphy, B., . . . Straughan, B. (2018). *Augmented and Virtual Reality Survey Report.* PerkinsCoie LLP.

Krämer, N. (2017). The Immersive Power of Social Interaction. In D. Liu, C. Dede, R. Huang, & J. Richards, *Virtual, Augmented, and Mixed Realities in Education* (pp. 55-70). Singapur: Springer.

Lau, K. W., & Lee, P. Y. (2015, November 27). The use of virtual reality for creating unusual environmental stimulation to motivate students to explore creative ideas. *Interactive Learning Environments, 23(1), 3-18.* Retrieved from http://dx.doi.org/10.1080/10494820.2012.745426

Liu, D., Bhagat, K. K., Gao, Y., Chang, T.-W., & Huang, R. (2017). The Potentials and Trends of Virtual Reality in Education. In D. Liu, C. Dede, R. Huang, & J. Richards, *Virtual, Augmented, and Mixed Realities in Education* (pp. 105-130). Singapur: Springer.

Mayes, & Fowler. (1999). Learning technology and usability: a framework for understanding courseware. *Interacting with Computers, 11,* 485-497.

Merchant, Z., Goetz, E., Cifuentes, L., Keeney-Kennicutt, W., & Davis, T. (2014, January). Effectiveness of virtual reality-based instruction on students' learning outcomes in K-12 and higher education: A meta-analysis. *Computers & Education, 70,* 29-40. doi:https://doi.org/10.1016/j.compedu.2013.07.033

Mikropoulos, T., & Natsis, A. (2011). Educational virtual environments: A ten-year review of empirical research (1999-2009). *Computers & Educations, 56,* 769-780.

Pantelidis, V. (2009). Reasons to Use Virtual Reality in Education and Training Courses and a Model to Determine When to Use Virtual Reality. *Themes in Science and Technology Education, 2,* 59-70.

Saleeb, N., & Dafoulas, G. (2011). Effects of Virtual World Environments in Student Satisfaction: An Examination of the Role of Architecture in 3D Education. *International Journal of Knowledge Society Research, 2(1)*, 28-48.

Sherman, W. R., & Craig, A. B. (2003). Understanding Virtual Reality: Interface, Application, and Design. San Francisco: Morgan Kaufmann Publishers.

Slater, M. (2003). A Note on Presence Terminology. Department of Computer Science . London: University College London. *Retrieved from* http://www0.cs.ucl.ac.uk/research/vr/Projects/Presencia/ConsortiumPublications/ucl_cs_papers/presence-terminology.htm

The Goldman Sachs Group, Inc. (2016). Profiles in Innovation, Virtual & Augmented Reality, Understanding the race for the next computing platform. New York: The Goldman Sachs Group, Inc.

BIOGRAPHICAL INFORMATION

Jörg Schminder is currently a Ph. D. student at the division of Applied Thermodynamics and Fluid Mechanics at Linköping University whose current research focus is within the field of thermal system and comfort management. In addition, he works at the university's pedagogic and didactic support center for university education (Didacticum) as an expert for information and communication technologies. He also is teaching and developing a course in Gas Turbine Engines, assist in basic fluid- and thermodynamic courses and supervise different type of theses.

Filip Nilsson *(M.Sc.),* ***Paulina Lundberg*** *(M.Sc.),* ***Nghiem-Anh Nguyen*** *(M.Sc.), and* ***Christoffer Hag*** *(M.Sc.)* were former mechanical engineering students at Linköping University.

Hossein Nadali Najafabadi *(Ph. D.),* is currently an assistant professor fellow at the division of Applied Thermodynamics and Fluid Mechanics, Linköping University, Linköping, Sweden. In addition to his research within the Turbomachinery field, he is involved in courses such as becoming a teacher in higher education, gas turbine engines, fluid mechanics, computational heat transfer, modelling and simulation of energy and heat transfer processes etc.

Corresponding author

Jörg Schminder
Linköping University
Department of Management and Engineering SE-58183 Linköping, SWEDEN
+46-13 28 17 62
jorg.schminder@liu.se