Sustainable Production through Advanced Manufacturing, Intelligent Automation and Work Integrated Learning, J. Andersson et al. (Eds.)
© 2024 The Authors.
This article is published online with Open Access by IOS Press and distributed under the terms of the Creative Commons Attribution Non-Commercial License 4.0 (CC BY-NC 4.0).
doi:10.3233/ATDE240207

Integration of Research on Immersive Learning Environments and Education in Welding

Daniel SJÖLIE[a], Zakarias DAMI MORTENSEN[a], Clara LARSSON[a], Tahira RAZA[b], Peigang LI[b] and Maria Asuncion VALIENTE BERMEJO[b] [1],
[a] *University West, School of Business, Economics and IT, SE-461 86 Trollhättan, Sweden*
[b] *University West, Department of Engineering Science, SE-461 86 Trollhättan, Sweden*
ORCiD ID: Daniel Sjölie https://orcid.org/0000-0002-3541-2019
Clara Larsson http://orcid.org/0000-0002-8675-019X
Zakarias Dami Mortensen https://orcid.org/0009-0007-1111-4723
Maria Asuncion Valiente Bermejo https://orcid.org/0000-0003-3374-6282

Abstract. The integration of virtual reality (VR) laboratories into welding education presents an array of potential advantages. It can be used at campus or in distance, and it offers an alternative when access to traditional laboratories is challenging. The economic benefits, including savings on material preparation and energy costs, along with the environmental, health and safety advantages of mitigating exposure to welding fumes, arc radiation, and electrical hazards, add further value and contribute to sustainability in welding education. The work presented here is an example of the integration of education in the areas of welding and informatics and research on immersive learning. A multidisciplinary team worked on the development of an immersive learning environment, including virtual laboratory areas for welding processes as well as for microstructural inspection of welds. During the project, this learning environment, and the contained virtual laboratories, have been implemented by the researchers with the support from IT students, and tested, and improved with the feedback provided by students in welding technology, materials science, and manufacturing courses. Overall, more than twenty students from Informatics have been involved throughout the project, resulting in five bachelor theses, three master theses, three course projects in Immersive computing, and two course projects focusing on web development. The involvement of IT students has not only supported the development of the virtual learning environment, but it has also created new avenues for future research and developments in immersive computing.

Keywords. Welding, immersive technologies, education, virtual reality

1. Introduction

Laboratory education is an essential pedagogical element of engineering studies, as it enables students to move from observation to understanding the principles and theories behind the phenomena [1]. Therefore, it helps students to learn and understand concepts, principles, and fundamental engineering skills [1,2]. Despite this important role, some

[1] Corresponding Author: Maria Asuncion Valiente Bermejo, asun.valiente@hv.se

limitations may hinder the ideal use of laboratories in education. For example, hands-on laboratories generally require significant investment in infrastructure, equipment, energy for the usage of the equipment, acquisition of material and consumables, the need for personnel to maintain the laboratory and teachers to assist the students, etcetera [3]. Nowadays, distance education has become a common modality in teaching and learning, and educators are adopting emerging technologies to create flexible educational environments to reach as many students as possible both nationally and internationally [4]. Like physical labs, virtual laboratories develop students' theoretical understanding, but they require lower investment and fewer resources whilst being safe [5–7]. Virtual labs are flexible and allow students to change the values of different variables and find the experimental results in a faster way than traditional hands-on experiments [8]. In addition, the usage of virtual reality (VR) in education is effective in enhancing processes such as engagement, motivation, confidence, creativity, and encouragement in completing tasks among students [9,10]. However, it is important to note that VR as a learning tool may not be equally effective for all students [9]. Factors such as cybersickness, trust, and acceptance of technology are some of the variables that can influence students' experiences and the effectiveness of learning in VR [11]. Still, it can be argued that the benefits outweigh the potential drawbacks as the incorporation of VR technology in education presents opportunities that cannot be reached through alternative media.

The integration of VR specifically into welding education offers a multitude of potential benefits, such as its capacity to provide a secure learning environment, particularly conducive to the exploration of welding tasks without being exposed to electrical shocks, welding fumes, and arc radiation. In addition, learning in VR can benefit students with better freedom in selecting and studying between different welding methods. Another benefit is the flexibility that the tool can bring both distance as well as on-campus education, where students don't have to be limited to specific locations or times. Furthermore, there are economic considerations that can be mitigated with the usage of VR, notably in terms of cost reductions associated with the acquisition of materials and tools [12].

Until now, the use of immersive technologies in welding education has mainly focused on the use of VR and AR (Augmented Reality) in welding simulators for training practical skills in welders [13–19]. However, the novelties of the work presented here are, on one hand, the construction of a complete virtual learning environment, including one laboratory in welding processes and another one in welding metallurgy, and on the other hand, the methodology used in the work, integrating students and researchers from informatics and engineering in the development of such virtual environment. Therefore, the focus is not on welding research, but on immersive learning and specifically on the use of the emerging digital technologies in welding education and how collaboration with students can be leveraged to address these challenges.

2. Background

It has been long since a group of researchers in welding had the vision to incorporate virtual reality laboratories in the welding courses offered at the master's in manufacturing engineering at University West. That vision was well aligned with one of the strategic objectives at the university, i.e., digitalization. The presence of immersive technologies at different education levels, from undergraduate to doctoral education, without excluding courses for professionals has been gradually increasing, and a dedicated laboratory for immersive technologies was established as a hub to promote interdepartmental collaboration. Within that environment, an interdisciplinary team formed by researchers in welding and researchers in immersive computing started to work together back in 2020. The work presented here is the result of that collaboration, which is referred to as WELD-VR project.

The main objective was the development of one virtual learning environment containing two lab areas, one for microscopy investigation of welds and another related to welding processes. After using the welding processes lab, the students should be able to learn how the welding parameters influence the quality of the resulting welds. By using the metallurgy lab, the students should learn about the microstructure of different metal alloys welded, while learning also about optical microscopy and sample preparation for metallographic inspection. Once the first version of the virtual learning environment was developed, the objective was to implement the virtual environment in relevant courses within the engineering department at different levels (see Chapter 3, Figure 1). The feedback from the engineering students was used to sequentially test, improve, adjust, and fine-tune the virtual environment.

In addition to the novelty of constructing a complete virtual learning environment in welding, in this manuscript, the focus is on the integration of education and research along the entire process: from the design of the learning environment to the implementation and improvement. Here it is detailed how IT students and Engineering students supported the researchers along the process.

3. Experimental: Methodology and Equipment

The first part of this chapter describes the methodology used in the project to ensure collaboration and the accomplishment of the objectives, whilst the second part of the chapter focuses on the tools and equipment used, including hardware and software.

The overall strategy in the construction of the learning environment was to develop it further and further continuously as an iterative process. The use of continuous improvement cycles is relatively new in the field of education [20], but it is well-known worldwide, as many quality management systems (i.e., ISO 9001) are based on the same iterative approach to ensure development and continuous improvement [21].

A representation of the continuous improvement cycle used in this project can be found in Figure 2. First, the project management identified areas/topics where the research project would need support from IT students. Consequently, a series of “student projects” were defined with specific scope and objectives, and these were offered to the students among the suitable available courses in computing (Figure 1). It is important to note that the suggested projects were offered as optional for the students and that some of the projects were not selected by them. While this presents some limitations it also makes it possible to integrate more adaptively into current activities and courses, widening the pool of available students and collaborations. The IT faculty members gave technical support and supervisory guidance to these students, providing them stability to finalize their prototypes. While conducting the students’ projects, and whenever it was needed, the IT students were getting support in the form of data, or access to the welding laboratories from the Engineering faculty. In the end, the results from the IT students’ projects were tested and evaluated within the WELD-VR research project, and some of them resulted in being implemented and/or integrated, whilst others were discarded.

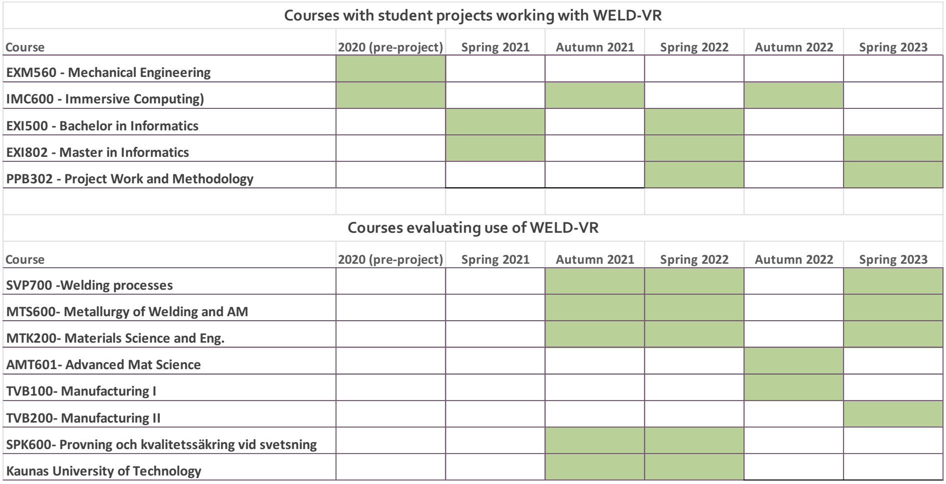
In parallel to this cycle, another loop within the Engineering side was taking place. The project management identified courses within the Engineering programs where the virtual environment could be relevant, and teachers and examiners were contacted to offer them the possibility for their students to test and evaluate the virtual reality laboratories as part of the courses. Figure 1 shows the list of courses and the timing where the VR laboratories were tested by the Engineering students. It is worth noting that participation in the VR labs was offered as optional for the students, as an addition to the campus labs that they already had in the curriculum. After each VR session with the Engineering students, they were asked to fill in a survey where, among other questions, they were asked to suggest improvements and identify bugs in the environment. IT faculty were also present during the VR labs with the Engineering students, and oral feedback in addition to written feedback was collected. That feedback was an important input to the research project for continuous development and improvement.

Working with emerging technologies involves the continuous development of tools. However, a core set of IT tools remained stable throughout the project. In terms of software, the central tool was Unreal Engine (https://www.unrealengine.com/), which was upgraded from Unreal Engine 4 to Unreal Engine 5 during the project time. The IT students were required to use Unreal Engine to facilitate the integration of their results into the WELD-VR project. For the students' projects focusing on the development of a webpage for managing learning material, common web development tools such as React (https://react.dev/), and SQLite (https://www.sqlite.org/), were used instead. Some students also used additional software, such as Reality Capture, (https://www.capturingreality.com/realitycapture) to explore generating 3D models of real environments to be integrated into the application.

The primary target hardware was the Meta Quest 2 headset (https://www.meta.com/se/en/quest/products/quest-2/). Students mostly used these headsets connected to Windows computers via Quest Link (a solution from Meta to connect standalone headsets like Quest 2 to a desktop computer), to facilitate quick prototyping and development. A version of the application was also developed to run directly on the mobile hardware of the Quest 2 headset. This was primarily developed by faculty from informatics, but students used it to become familiar with the existing application, and in some cases to run user studies. This was also the version of the application most engineering students evaluated in connection with the welding and metallurgy courses. The further potential of the virtual reality environments was explored by creating versions for more advanced hardware, such as the Varjo XR3 (https://varjo.com/products/xr-3/), and at the end of the project, the Meta Quest Pro headset (https://www.meta.com/se/en/quest/quest-pro/) was used too.

4. Results: Contributions of the IT students

Throughout the project, 26 students have contributed to its development and related research. In addition to thesis projects on three different programs, two bachelor level and one master level, two project courses had students accepting to work with WELD-VR student projects. One was a master's course focusing on immersive computing and students of this course contributed significantly to the implementation of new content and functionality for the VR application. The other course was a bachelor's course for system development students, with student projects implementing most of the webpage serving as an interface for learning material for the application.



Courses with student projects working with WELD-VR						
Course	2020 (pre-project)	Spring 2021	Autumn 2021	Spring 2022	Autumn 2022	Spring 2023
EXM560 - Mechanical Engineering						
IMC600 - Immersive Computing)						
EXI500 - Bachelor in Informatics						
EXI802 - Master in Informatics						
PPB302 - Project Work and Methodology						

Courses evaluating use of WELD-VR						
Course	2020 (pre-project)	Spring 2021	Autumn 2021	Spring 2022	Autumn 2022	Spring 2023
SVP700 -Welding processes						
MTS600- Metallurgy of Welding and AM						
MTK200- Materials Science and Eng.						
AMT601- Advanced Mat Science						
TVB100- Manufacturing I						
TVB200- Manufacturing II						
SPK600- Provning och kvalitetssäkring vid svetsning						
Kaunas University of Technology						

Figure 1. Courses connected to the project, including both courses with IT related student projects and courses at the Engineering department where the virtual environments were tested.

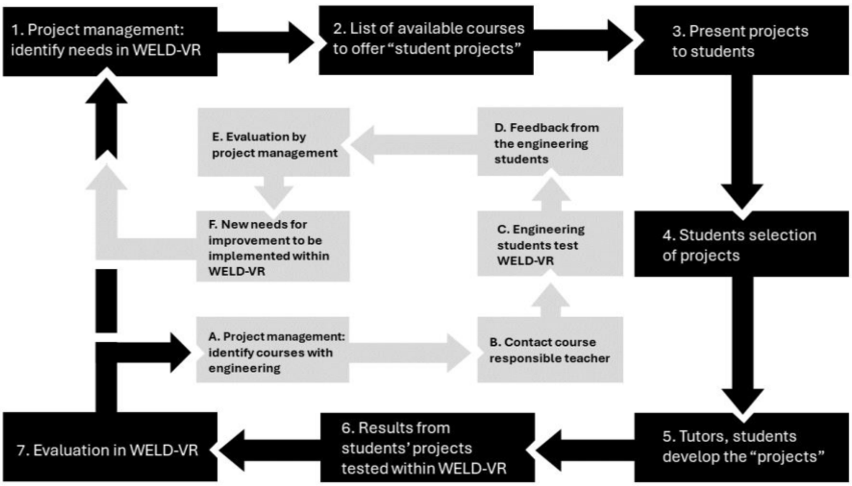


Figure 2. Methodology used in the project for continuous improvement. The black corresponds to IT students' whilst grey corresponds to engineering students' activities in relation to the project.

4.1. Student contributions to iterative development

Several of the student projects included implementations in Unreal Engine that could be directly integrated into the main WELD-VR project. One of the initial ambitions that led to the creation of the WELD-VR project was to capture the experience of a study visit to the labs working with welding and metallurgy at the university. Thus, the first student project focused on replicating realistic equipment and combining this with some inspection of metallurgy images in a Virtual welding lab ([22], project #1, Table 1). For example, photogrammetry was used to create digital models of a welding robot and a microscope from the metallurgy lab. These models were included in the project for a long time, though much of it was further developed or replaced with improved versions as development progressed.

In project #2 (Table 1), students focused on how the learning environment could be improved by dividing the initial combined learning environment into two different rooms, each with a specific topic: one room for welding, and one for microscopy (Figure 3). The students also added 360-degree images from real industry environments, rather than walls in the two rooms, making the rooms appear more familiar to users. A “teleportation hub” was also implemented as a starting point in the virtual environment, where each of the stations had a designated area in which the visitor could walk in to get teleported to the room of choice. It can be noted that project #2 used material from the first project, both images collected and some of the captured models. The two learning stations developed here are still present in the project today, in developed forms, and the 360-photos are still used, though with other setups. These 2 initial student projects were both conducted before the start of the main WELD-VR project and exemplify the core contribution of students to the project both its initiation and continued development.

Table 1. Student projects contributing to development and research connected with the WELD-VR project. **Dev**: Projects primarily implemented functionality directly used in project development**. Res**: Projects primarily contributing literature research and studies informing academic research and further writing. See Figure 1 for a full listing of the courses involved. Titles in italics are translated.

#	Title	Students	Course	Type
1	Virtual Welding Lab [22]	1	EXM560	Dev
2	Designing a welding learning environment	3	IMC600	Dev
3	“I immediately experienced a more warming welcome and it felt more alive.”: A study on emotional design and colours in a virtual reality setting. [23]	1	EXI802	Res
4	*Virtual realities as educational tools for students in welding and metallurgy: A study around WELD-VR with avatars and agents in focus* [24]	2	EXI500	Res
5	*Customization of learning modules in a VR environment: A study on WELD-VR* [25]	2	EXI500	Res
6	*Streamlining VR training with interaction and realism: Virtual reality as an educational tool in metallurgy and robotic welding* [26]	2	EXI500	Res
7	Avatars for learning in VR	1	EXI500	Res
8	User experience in a VR learning environment	1	IMC600	Dev
9	Animated elements for exploration and navigation in educational VR – A Mixed Method Study [27]	1	EXI802	Res
10	WELD-VR-TOOLS (webpage)	5	PPB302	Dev
11	*A study in haptic and visual feedback for WELD-VR* [28]	2	EXI500	Res
12	Guiding users in VR, with videos or avatars	2	IMC600	Dev
13	Design principles for embodied pedagogical agents – Scenario based learning for virtual reality [29]	1	EXI802	Res
14	WELD-VR (webpage)	6	PPB302	Dev

In spring 2021 one master thesis and four bachelor theses were completed ([23–26], projects #3-7, Table 1). The topics of these theses were grounded in needs and research questions of interest as identified throughout the WELD-VR and will be discussed further below. More direct contributions to the development came from project #8 (Table 1), focusing on user experience and natural guidance in the environment. Grounded in user experience research, the student designed and redesigned several items, making it easier to use and understand the virtual environment. This included industrial-looking marks on the floor and the improving user interaction in the learning stations with implementations in Unreal Engine that could be directly integrated (Figure 4).

As the project was continually tested with engineering students, the need for additional guidance and user support in the application was further highlighted. Spring 2022 saw several student projects, including one master thesis [27] (project #9, Table 1) and one bachelor thesis [28] (project #11, Table 1) addressing this issue. Both works included some prototyping and were valuable explorations to guide project development, but were challenging to integrate into the live application and will be further described below.

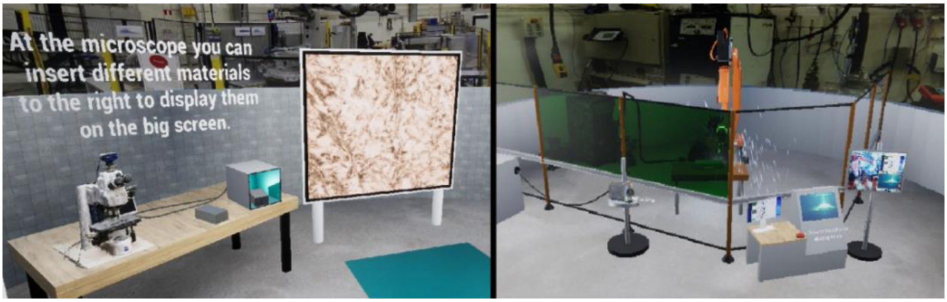


Figure 3. Two rooms designed for learning about metallurgy (left) and welding processes (right) respectively.

Figure 4. Markings and guiding text on the floor, similar to in many industrial settings, is one example of User Experience improvements implemented as student work in project #8.

Another realization coming from continued development and testing was a need for teachers to be able to add, view, and edit materials in the virtual environment without any coding knowledge. This prompted the suggestion of a student project to create a webpage designed for teachers and educators to easily upload and modify material. The project was accepted by students in a course in Project Work and Methodology and completed in spring 2022 (project #10, Table 1). This project included both the development of a frontend webpage and a backend with a database and an API that the immersive WELD-VR application could use to get the updated data easily. Although some additional work was required to complete the integration, the bulk of the website implemented by the students was implemented (Figure 5, left).

In the last year of the project, a course project in the Immersive Computing course took another look at methods for better guidance in the application, with prototypes for both improved use of videos on virtual 2D monitors and potential use of 3D-avatars animated through recorded movements by instructors (project #12, Table 1). These prototypes have yet to be implemented in the main project but are promising starting points for improvements. The design principles embodied pedagogical agents that were further investigated in a master thesis [29] (project #13, Table 1) and provided an additional basis for continued development in this direction.

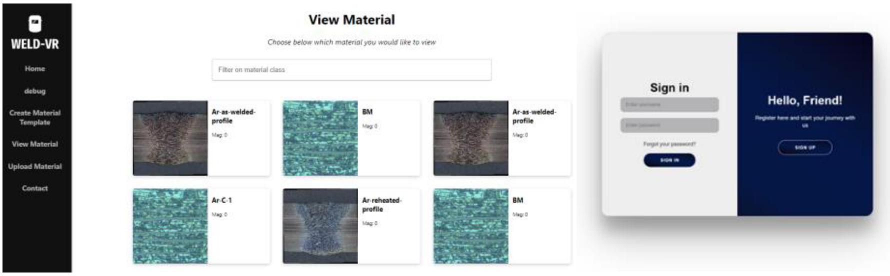


Figure 5. The website showing the list of current metallurgy materials in the database (left) and the redesigned login page (right)

Finally, an additional course project in the Project Work and Methodology course focused on improving the design of the webpage and working on quality assurance (project #14, Table 1). This project focused on how teachers and students could navigate the website easier. It redesigned several pages on the site, including the landing page (Figure 5, right), and was a critical contribution to making the webpage useable by teachers. As these students worked on a direct copy of the existing website it was easy to integrate.

4.2. Research contributions

The depth and breadth of theoretical contributions from both Bachelor and Master theses have been crucial in laying a scholarly foundation for the WELD-VR project. These contributions have not only informed the practical developments within WELD-VR but have also expanded a theoretical framework that paves the way for future academic investigations.

Two separate bachelor's theses investigated the educational potential of avatars and agents within the VR setting, specifically targeting welding and metallurgy education [24] (works #4 and #7, Table 1). Additional theses focused on the customization of learning modules, allowing for a more tailored educational experience [25] (project #5, Table 1) and explored enhancing training efficiency through increased interaction and realism [26] (project #6, Table 1). A final bachelor thesis delved into haptic and visual feedback mechanisms to improve user engagement [28] (project #11, Table 1). Interviews and literature gathered by this thesis work provide a valuable basis for consideration in continued work with the project.

Figure 6. Two versions of the WELD-VR environment, one with muted, greyscale colors (Right), and one with strong saturated colors (Left).

The first master thesis [23] (project #3, Table 1) focused on how colors could change users' perception of the virtual environment, and how such design elements could be incorporated to induce positive emotions and increase learning outcomes. This was investigated by using 2 experimental versions of WELD-VR and a mixed-method approach. One version with muted, grayscale colors, and one with vivid orange color (Figure 6). The thesis revealed a preliminary but interesting impact of color, with saturated hues being more associated with pleasant but unserious applications. The study exemplifies the potential impact of emotional design within VR learning environments.

Figure 7. Prototype work exploring novel implementations for user guidance. Here showing an animated cloud of particles, highlighting an area to explore like fireflies.

Further work in a second master thesis [27] (project #9, Table 1) focused on the complexities of interaction design in educational VR, investigating the use of animated elements like arrows and particle swarms to guide user exploration (Figure 7). The mixed-method study concluded that animated cues may support exploration in VR and include reasoning on a knowledge gap in transitioning from 2D to 3D educational experiences.

A final master thesis examined the role of pedagogical agents in VR for scenario-based learning [29] (project #13). Utilizing semi-structured interviews, the study derived four design principles for these agents, such as leveraging the Six Degrees of Freedom and ensuring familiarity in the virtual environment. These principles offer a concrete framework for future VR educational designs.

In summary, these theses contribute a rich academic basis to WELD-VR. They not only guide its practical evolution but also extend its academic footprint, creating avenues for future research and implementation.

5. Discussion

While the integration of student projects into the WELD-VR research project enabled many interesting explorations and greatly expanded what could be implemented, there were limitations and challenges. One limitation was set by the availability and timing of IT courses, which were not always in alignment with the project's needs. In addition, topics arising from the project were offered to the IT students as *optional* student projects. Thus, not all the topics identified in the research project were selected by the students. This has been a limiting factor in the capability to steer the exploration of new features and areas. Also, the courses have their own learning objectives, and the students' projects offered had to be aligned with the course syllabuses. In terms of testing the virtual laboratories, courses in manufacturing, materials science, and metallurgy were offered throughout the whole project (see Fig. 1), making it possible to test the virtual labs throughout the project time. It is important to note that participation in testing the VR labs was an optional activity for the engineering students. Despite this, the testing sessions were in general very well attended, probably for the extra motivation and engagement that VR generates among students in the beginning [9,10]. It is out of the scope of this paper to analyze the feedback given by the engineering students to the development of the virtual environment, but this project has opened a new era of opportunities in the pedagogics used in the welding and metallurgy courses. Now that the virtual environment is fully operational, teachers can decide to include the VR labs as regular course activities for the engineering courses.

For those teaching engineering courses, several workshops and training activities have been specifically offered during the project. However, despite the overall initial positive acceptance from this group, some resilience to implement the labs as regular course activities has been observed. The literature suggests [30] that software usability is one of the main reasons for the low use/implementation of VR in education. Although a proper investigation of this resilience is future work, it can be noted that there is much potential for improved usability in emerging technologies such as VR. For example, navigation in the virtual environment has been made simpler throughout the project, and recent hardware allows for better hand-tracking and the potential to side-step complex interactions with the hand-controllers that are normally required.

In addition to students and teachers, another key component to consider was the tools and resources required to conduct the project. A dedicated laboratory for immersive technologies (Open lab) at University West served as a hub to enable interdepartmental collaboration among welding and IT faculty, while also providing students access to the necessary hardware and software. Interactions between students and IT faculty were also facilitated by this shared space. This level of access was crucial for the success of the students' projects and for the testing of the virtual environment. An additional aspect to consider is that consequently the IT students have had the opportunity to use state-of-the-art equipment (hardware and software) within a real immersive computing project, and that is an important element of Work Integrated Learning (WIL) in our education that promotes students' future employability [31].

Aspects such as flexibility, applicability, and sustainability are intimately connected in this project. From the start, it was clear to the project team that the project time was finite, but that the virtual labs should be self-sustainable after the end of the project. That drove the project management to offer the "web project" to the IT students (works #10 and #14 in Table 1), where engineering teachers can modify the database of microstructures at any time and keep the lab constantly updated with new alloys and new images. In addition, these virtual reality labs allow the teachers to adjust the learning objectives at different levels, and therefore, vocational school students, undergraduates, masters, and industrial students can benefit from the labs. That enhances the applicability and flexibility of this virtual environment.

Whilst the direct contribution to the WELD-VR application in the form of programming and prototyping was of great value; it is important to highlight the benefits gained via the more indirect influence on the students had on the research and development of the project. Even if specific students works were not used directly in the implementation of the application, their discoveries, perspectives, and research influenced and inspired decisions made by the project team and improved the application. Thus, all student contributions were of great value to the project. The project team and the students learned and benefited from each other, and their contributions provided guidance for further development and research on the topic.

6. Conclusions

The work presented here is a successful example of collaboration and integration of research in the field of immersive technologies and education in the areas of welding and informatics. The collaboration with IT students made it feasible to develop novel solutions for digital education, evaluate them in the context of welding education and explore a multitude of challenges in this setting. As a result of the collaboration:

- An immersive learning environment including virtual laboratory areas for welding processes and welding metallurgy was developed.
- The large number of IT students involved throughout the project resulted in several bachelor theses, master theses, and course projects. That involvement not only supported the development of the virtual learning environment, but the creation of new avenues for future research and developments in immersive computing.

References

[1] Bates AW (Tony). Teaching in a Digital Age - Second Edition [Internet]. Tony Bates Associates Ltd.; 2019 [cited 2023 Sep 22]. Available from: https://pressbooks.bccampus.ca/teachinginadigitalagev2/.
[2] Feisel LD, Rosa AJ. The Role of the Laboratory in Undergraduate Engineering Education. J Eng Educ. 2005;94:121–130.
[3] Melkonyan A, Gampe A, Pontual M, et al. Facilitating Remote Laboratory Deployments Using a Relay Gateway Server Architecture. IEEE Trans Ind Electron. 2014;61:477–485.
[4] Heradio R, de la Torre L, Galan D, et al. Virtual and remote labs in education: A bibliometric analysis. Comput Educ. 2016;98:14–38.
[5] Potkonjak V, Gardner M, Callaghan V, et al. Virtual laboratories for education in science, technology, and engineering: A review. Comput Educ. 2016;95:309–327.
[6] Olympiou G, Zacharias Z, deJong T. Making the invisible visible: enhancing students' conceptual understanding by introducing representations of abstract objects in a simulation. Instr Sci. 2012;41:575–596.
[7] Gomes L, Bogosyan S. Current Trends in Remote Laboratories. IEEE Trans Ind Electron. 2009;56:4744–4756.
[8] Zacharia ZC, Olympiou G, Papaevripidou M. Effects of experimenting with physical and virtual manipulatives on students' conceptual understanding in heat and temperature. J Res Sci Teach. 2008;45:1021–1035.
[9] Abich J, Parker J, Murphy JS, et al. A review of the evidence for training effectiveness with virtual reality technology. Virtual Real. 2021;25:919–933.
[10] Hu-Au E, Lee JJ. Virtual reality in education: a tool for learning in the experience age. Int J Innov Educ. 2017;4:215–226.
[11] Borsci S, Lawson G, Broome S. Empirical evidence, evaluation criteria and challenges for the effectiveness of virtual and mixed reality tools for training operators of car service maintenance. Comput Ind. 2015;67:17–26.
[12] Jang J, Ko Y, Shin WS, et al. Augmented Reality and Virtual Reality for Learning: An Examination Using an Extended Technology Acceptance Model. IEEE Access. 2021;9:6798–6809.
[13] Yang U, Lee GA, Kim Y, et al. Virtual Reality Based Welding Training Simulator with 3D Multimodal Interaction. 2010 Int Conf Cyberworlds. 2010. p. 150–154.

[14] Chan VS, Haron HNH, Isham MIBM, et al. VR and AR virtual welding for psychomotor skills: a systematic review. Multimed Tools Appl. 2022;81:12459–12493.
[15] Tran N-H, Nguyen V-N, Bui V-H. Development of a Virtual Reality-Based System for Simulating Welding Processes. Appl Sci. 2023;13:6082.
[16] Wells T, Miller G. The Effect of Virtual Reality Technology on Welding Skill Performance. J Agric Educ. 2020;61:152–171.
[17] Wang W. Design and implementation of welding training simulation platform based on virtual reality technology. Int Conf Mechatron Eng Artif Intell MEAI 2022 [Internet]. SPIE; 2023 [cited 2023 Sep 22]. p. 35–40. Available from: https://www.spiedigitallibrary.org/conference-proceedings-of-spie/12596/1259607/Design-and-implementation-of-welding-training-simulation-platform-based-on/10.1117/12.2671859.full.
[18] Li R, Zhou L, Quan J, et al. Exploration on the Application of Numerical Simulation and Virtual Reality Technology in Welding Training Teaching. 2023 [cited 2023 Sep 22]. Available from: https://eudl.eu/doi/10.4108/eai.23-12-2022.2329109.
[19] Reality based skills development approach in welding technology: An overview. Mater Today Proc. 2021;47:7184–7188.
[20] Tichnor Wagner A. Future of Education and Skills 2030: Curriculum Analysis: Connections between Anticipation-Action-Reflection and Continuous Improvement Cycles. Paris, France: OECD Organization for Economic Co-operation and Development; 2018. p. 18. Available from: https://www.oecd.org/education/2030/Connections-between-Anticipation-Action-Reflection-and-Continuous-Improvement-Cycles.pdf.
[21] Deming WE. Elementary Principles of the Statistical Control of Quality: A Series of Lectures [Internet]. Nippon Kagaku Gijutsu Remmei; 1950. Available from: https://books.google.se/books?id=lZhXnQAACAAJ.
[22] Kumar K. Virtual Welding Lab [Internet]. 2020 [cited 2023 Oct 13]. Available from: https://urn.kb.se/resolve?urn=urn:nbn:se:hv:diva-15872.
[23] Mortensen Z. “I immediately experienced a more warming welcome and it felt more alive.” : A study on emotional design and colours in a virtual reality setting. [Internet]. 2021 [cited 2022 Mar 3]. Available from: http://urn.kb.se/resolve?urn=urn:nbn:se:hv:diva-16638.
[24] Löfström D, Nilsson M. Virtuella verkligheter som läromedel för studenter inom svetsning samt metallurgi : En studie kring WELD-VR med avatarer och agenter i fokus [Internet]. 2021 [cited 2023 Oct 13]. Available from: https://urn.kb.se/resolve?urn=urn:nbn:se:hv:diva-16554.
[25] Magnusson V, Vrban D. Anpassning av inlärningsmoment i VR-miljö: En studie på Weld-VR [Internet]. 2021 [cited 2023 Oct 13]. Available from: https://urn.kb.se/resolve?urn=urn:nbn:se:hv:diva-16807.
[26] Yohannes B, Wrede G. Effektivisera VR-träning med interaktion och realism : Virtual reality som utbildningsverktyg inom metallurgi och robotsvetsning [Internet]. 2021 [cited 2023 Oct 13]. Available from: https://urn.kb.se/resolve?urn=urn:nbn:se:hv:diva-17841.
[27] Pedersen L. Animated elements for exploration and navigation in educational VR : A Mixed Method Study [Internet]. 2022 [cited 2023 Oct 17]. Available from: https://urn.kb.se/resolve?urn=urn:nbn:se:hv:diva-18639.
[28] Lenberg H, Jubell S. En studie i haptisk och visuell feedback för WELD-VR [Internet]. 2022 [cited 2023 Oct 13]. Available from: https://urn.kb.se/resolve?urn=urn:nbn:se:hv:diva-19006.
[29] Löfström D. Design principles for embodied pedagogical agents : Scenario based learning for virtual reality [Internet]. 2023 [cited 2023 Oct 13]. Available from: https://urn.kb.se/resolve?urn=urn:nbn:se:hv:diva-20588.
[30] Kavanagh S, Luxton-Reilly A, Wuensche B, et al. A Systematic Review of Virtual Reality in Education. Themes Sci Technol Educ. 2017;10:85–119.
[31] Ng B. Future Directions for Research in Graduate Employability and Workplace-Based Learning Development. In: Ng B, editor. Grad Employab Workplace-Based Learn Dev Insights Sociocult Perspect [Internet]. Singapore: Springer Nature; 2022 [cited 2023 Oct 11]. p. 193–197. Available from: https://doi.org/10.1007/978-981-19-5622-5_12.