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BLENDED LABORATORIES FOR JOINING TECHNOLOGY

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ABSTRACT

Laboratory training is an essential part of most Engineering Education programs and amplified by the Covid-19 crisis, educational institutions are increasingly exploring blended and online laboratories as an alternative or complement to pure on-side learning environments. In this paper, we report on the (re-) design, implementation and evaluation of a blended laboratory concept in joining technology. The laboratory consists of three interlinked pillars and builds conceptually on the flipped classroom approach. We evaluate student learning and satisfaction as well as teacher experiences in the new learning design based on student evaluations and performance data as well as teacher reflections. The results show that the new laboratory improved the average grade of students by 12% compared to the traditional set-up, which we attribute to the increase in active learning. Students also report high satisfaction with the new format and appreciate the flexibility and accessibility of the online learning materials. Qualitative analysis indicates, however, that successful participation in the flipped format is coupled to high degree of self-regulated learning skills. Further, teachers partly had difficulties to ensure active participation in the synchronous online sessions. Despite these issues, we conclude that the presented flipped laboratory concept is an excellent format to combine the advantages of online learning with the hands-on experience of physical laboratory work. By utilizing the benefits of online learning, this format reduces the time students spend passively listening to lectures and more than doubles the time spent on active learning and practice.

KEYWORDS

Online laboratories, Flipped classroom, Online learning, Blended learning, Robotic Welding
Standards 5, 6, 8

INTRODUCTION

Laboratory training is an important part of engineering education programs, as it allows students to acquire practical skills and knowledge through exploration, experimentation, and reflection in an inquiry-based learning environment (Hofstein & Lunetta, 2004) including analysis, creativity, and teamwork skills (Mohammed, et al., 2020). Traditional laboratory environments have been shown to have numerous benefits for students, including improved understanding of course material and enhanced problem-solving abilities. However, these environments also come with their own set of challenges, such as high costs, limited access and safety risks. As a result, and amplified by the Covid-19 crisis, educational institutions have been turning to blended and online laboratories as alternatives or supplements to in-person learning environments (Graham, 2018; 2022). In this paper, we present the design, implementation, and evaluation of a blended laboratory concept in joining technology, an interdisciplinary course module that incorporates elements of materials science, electrical engineering and construction. Pedagogically, the laboratory is based on the flipped classroom approach, where students prepare at home for more active learning in the on-site laboratories (Stöhr & Adawi, 2018). The learning design consists of three pillars: (1) asynchronous online learning activities, (2) synchronous digital live demonstrations, and (3) on-site presence laboratories featuring augmented reality-based and real welding exercises. Based on data from student assessments and evaluations, we examine the benefits and challenges of the new learning design in comparison to traditional laboratories.

STATE OF THE ART

Online laboratories are a type of e-learning tool that allows students to perform experiments and simulations remotely using real or simulated equipment. According to Chen et al. (2010), one can distinguish two basic approaches: remote labs and virtual labs. Remote labs involve real equipment that are controlled remotely through the internet using predefined gateways (directly or via a livestreamed instructor in the laboratory). The experiments can be followed live via video transmission and real measured values would be determined (Burdinski & Schifftler-Weinle, 2020). Virtual labs refer to simulated lab environments based on software and streaming approaches. A number of studies have been conducted on the advantages and disadvantages of these online lab alternatives, as well as their effect on student learning. One of the main benefits of online laboratories is that they can provide learners with access to a wide range of equipment and resources that may not be available in their local environment, which is especially valuable for learners in disadvantaged or underserved areas (Correia et al., 2018). Similarly, Nedic et al. (2003) and Post et al. (2019) found that remote and virtual labs are low-cost alternatives, providing flexibility and accessibility for students. Lynch and Ghergulescu (2017) and Potkonjak et al. (2016) noted that remote and virtual labs are resistant to damage and have simplified maintenance of lab facilities. Several studies have demonstrated the effectiveness of online laboratories in promoting learning. For example, a study by Rios and colleagues (2017) found that online laboratories can enhance learners' understanding of scientific concepts and improve their problem-solving skills. Correia et al. (2018) found that online laboratories can promote the development of critical thinking skills and increase learner engagement. Bartocci et al. (2011) found that virtual labs can enable students to participate in inquiry-based learning to formulate and examine hypotheses, and West and Veenstra (2012) found that students appreciate the ability to repeat experiments at their own pace.

However, Lynch and Ghergulescu (2017) and Potkonjak et al. (2016) also noted that virtual laboratories lack a real-life feel and can lead to oversimplifications if designed or implemented incorrectly. Students work only with a model representation of the real experiment (Burdinski & Schifftler-Weinle, 2020) and miss the experience of experimenting on real machines. The measured values can also differ greatly from real values and data generated in virtual labs tends to lack variation (Lewis, 2014). Sources of error from the real laboratory are eliminated so that students do not learn how to deal with incorrect measured values. Another challenge of online laboratories is the need for learners to have access to appropriate technology and internet connectivity (Correia et al., 2018). Finally, the switch from face-to-face to online laboratories is proving to be difficult for teachers. In a recent survey (Krämer & Hammerich, 2020), 80% of the lecturers stated that they perceive practical tests and experiments to be particularly limited by online teaching. In addition, 17% of them feared that most students will be significantly behind in learning

Overall, studies have shown that remote and virtual labs can provide equal or better learning outcomes for students compared to traditional labs (Brinson, 2015; Post et al., 2019). However, the design of online laboratories can have a significant impact on learning outcomes. Effective online laboratories should be interactive and provide learners with opportunities for experimentation and exploration (Rios et al., 2017). They should also include appropriate guidance and support, such as feedback and instructional materials, to help learners navigate the learning process (Correia et al., 2018). It is also important to note that there are little concepts or studies in the literature for the digitization of laboratories with large and dangerous equipment such as joining technology. The transfer of concepts (such as simple circuits or experiments), especially from the field of physics, electrics, or computer science to laboratories such as manufacturing technology, forming technology, joining technology, etc. is not easily possible. Thus, there is a need for further research to understand students' experiences using online and blended labs and to provide design recommendations for creating a more positive learning environment in this field.

CONTEXT: THE PROBLEM WITH THE JOINING TECHNOLOGY LABORATORY

Joining technology as an example for laboratories with heavy and dangerous equipment, is an interdisciplinary module that based on competencies from subjects such as materials science, electrical engineering, and construction. The laboratory units contribute to the application and deepening of the theory with practical exercises to provide a better understanding about different processes of joining. At the end of the module, students should be able to distinguish and evaluate different joining and cutting processes, explain how they work and, to a certain extent, apply them themselves. The entire module is worth five ECTS points. Due to the number of students and the limited resources, practical knowledge is not imparted to the same quality for all participants. As illustrated in Figure 1, a laboratory group consists of up to 15 students who are expected to observe, listen and understand the interaction between process, handling and types of errors within practical demonstrations.

During the laboratory exercises, students and instructors are confronted with challenges due to smoke gases, sparks, noise, obstructed vision, noise and acoustics etc. In particular, the visual impairment and the poor acoustics are main reasons for the inadequate transfer of knowledge from instructors to students. Due to the size of the group, the students cannot fully experience the practical demonstration as only the few students who have a clear view. A welding mirror or a welding helmet must be worn during welding to protect the eyes. As a result, the arc can be observed without endangering the eyes, however phenomena such as the distance between the torch and base material as well as the torch guidance are not sufficiently recognizable. The environment would be blurred by the evaporated smoke gas during welding. This means that important explanations can only be partially observed by the students. To carry out the laboratory exercises, the ventilation system must be switched on to evacuate the smoke gases. The resulting background noise and the noises that occur during welding make it difficult to understand the explanations properly, leading to insufficient transfer of knowledge to students. The instructor explains the important aspects while welding and wears a welding helmet for eye protection. The instructor's voice is muffled by the helmet and is overlaid by the background noise. Accordingly, only the very attentive students in the immediate vicinity of the instructor can pick up all the important information. In addition to the difficulties in the practical transfer of knowledge, students also had demands for improvement. According to the surveys from 2018 and 2019, 89% of the students wanted to increase the proportion of self-welding. They also expressed that the theoretical part of the laboratories should be reduced to a minimum, since those contents were explained in the lectures. However, despite those challenges, laboratories are elementary components of applied instructing and are highly valued by students.

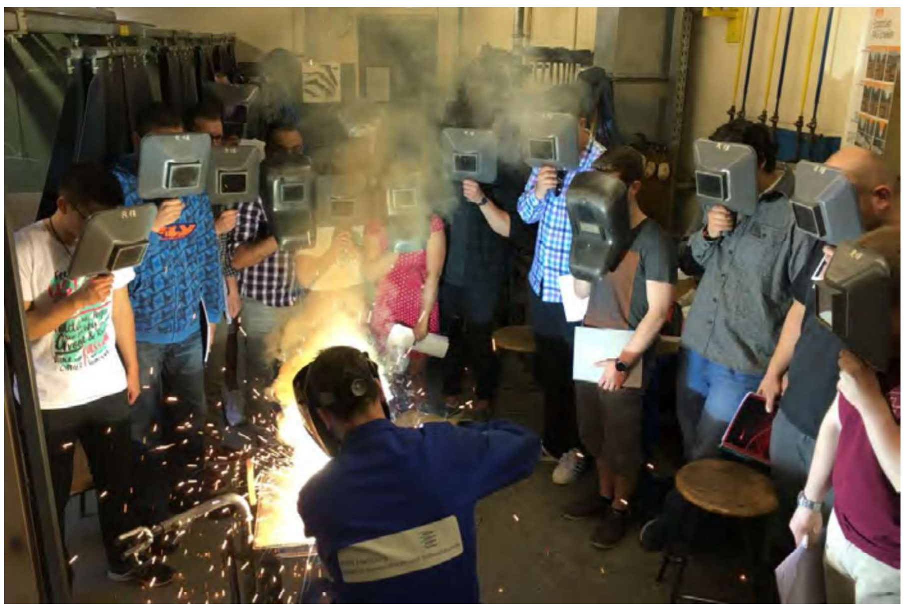

Figure 1: A typical laboratory for welding

DESIGNING A NEW LABORATORY FORMAT

The pandemic situation in the summer semester of 2020 required a fundamental redesign of the concept of the laboratories for joining technology. As part of student projects, an overall concept was developed to optimize the transfer of knowledge and overcome the above-mentioned challenges and restrictions. Learning outcomes and credits thereby remained the same as in the traditional format. Different formats such as explanatory videos, virtual tours, augmented reality, and digital live presentations were combined into an overall concept for the laboratories consisting of the following interlinked pillars:

1. Virtual laboratories + learning outcome online tests
2. Online presence laboratories + protocol + learning outcome online tests
3. On-site presence laboratories: Welding using augmented reality and real welding

After as short description of the technical set-up, we will describe the three pillars in more detail.

Technical set-up

For the first and second pillar, a trained laboratory staff is needed to use and integrate cameras and microphones. Moreover, the cameras and microphones used must be suitable for the special environment (brightness, noise, smoke, heat, sparks, etc.) of welding. In particular, it is revealed that a self-focusing camera is the most problematic one during welding, as the videos became unusable due to the automatic focusing. On the other hand, fixed focus cameras are not precise enough when close-up shots had to be shown. The brightness of the welding process is another challenge to recode digital laboratory materials (offline or online videos). Using a filter would reduce the brightness and make the welding process watchable, however, the overall view of the welding process is thereby impaired or hindered.

As already explained, welding by-products such as smoke and radiation as well as brightness require the use of a welding helmet. This protects the instructor during the practical demonstration. In addition, the fume extraction must be switched on in order to discharge the welding gases. Both the welding helmet and the smoke evacuation system prevent a sound transmission. In the primary recordings, the instructor's explanations and the characteristic noises during welding were drowned out by the fume extraction system. Also, the type of microphone influences the sound quality of recorded videos. Using a wireless microphone has the advantage of free moving however the disadvantage of sound missing or delay sound transmission. As a result of the first study there was a need for three cameras and two microphones (both equipped with surrounding noise cancelling) to better capture the real welding atmosphere. For the arrangement of the online presence laboratories, a software was necessary to integrate different perspective on one monitor. The freeware software OBS was chosen since it was already used for the theoretical lectures.

The equipment used to produce the videos both for virtual and online presence laboratories are schematically depicted in Figure 2. The best quality was produced by having two lecturers (nr. 1 and 2. in Figure 2). The main lecturer (1) performs the welding and explains issues during welding. Nr. 2 is the assistant lecturer who takes care of the Open Broadcaster Software (OBS) (nr. 7). The assistant is also responsible for the arrangement of the cameras, their repositioning, if necessary, as well as observing the chat monitor. To assure an acceptable video and sound quality, there is a need of using three cameras (nr. 4, 5 and 6). The sound is transmitted using a microphone in the helmet of the main lecturer. This way, the explanations made are clearly understandable. The welding sound was captured by a microphone attached to camera nr. 4. This microphone with a surrounding noise-canceling eliminated most of the disturbing sound of the fume extraction system.

The set up shown in Figure 2 was essential for online presence laboratories, since the students joining the laboratory from home had to clearly see and understand the correlation of the welding appearance and set parameter. The chat function enables an interactive laboratory. For the execution of the virtual laboratories the same set up was used.

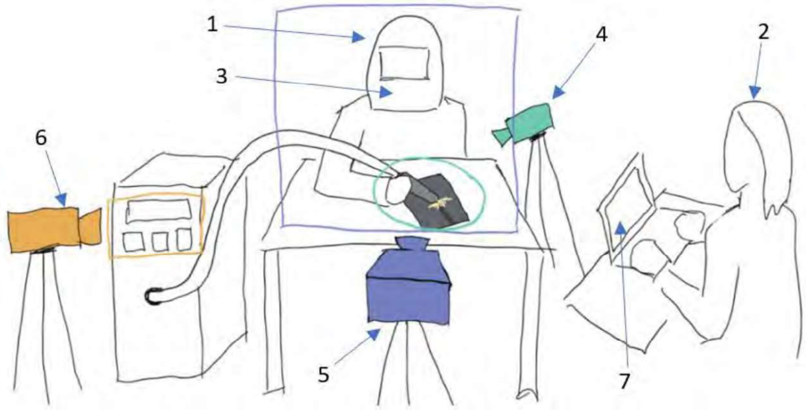

Figure 2: Schematic set up of a welding laboratory

Within the laboratories, different key processes of joining are demonstrated and explained. After a certain training of the laboratory staff first digital laboratories presented in June 2020. In the following, the content of the different laboratory types (interlinked pillars) is explained.

Pillar 1: Virtual laboratories

The virtual laboratories have been designed considering parts of flipped lab concept, where the theoretical lecturing part is moved outside the classroom to free more room for active learning (Stöhr & Adawi, 2018). The virtual laboratories are created as self-study module and include pre-selected video material and short texts. Following best practices of video production in online education (e.g., Guo et al., 2014), the basics of each process are explained in short videos with a length of three to five minutes. The short descriptions enable students a better understanding of the process. For each of the above-mentioned processes, explanatory videos have to be produced which is a time-consuming step. Therefore, as a first approach, available videos on YouTube had been evaluated. These videos and explanatory texts are presented to the students using a Moodle platform of the university. The so-called Emil-Room contains all necessary information for the students for each individual module. Therefore, the necessary files for the virtual laboratories are uploaded in the Emil-Room, available for registered students. The total working load of this part is about two to four hours for the students. The pillar of virtual laboratories is completed through a successful multiple-choice test and students are provided with test functions as a gate to pass on to the second pillar of the laboratory event.

Pillar 2: Online presence laboratories

This type of laboratory is designed as a live stream with live interacting students from home. Students are asked to suggest the welding parameters and the main lecturer demonstrates the welding and discusses visible correlations with the students. The main lecturer emphasizes certain phenomena of welding such as arc type or formation of silicon nitride, sparks etc. The main aim of this laboratory with a total working hour of 10 is to evaluate meaningful parameters together with the students and demonstrate the result of those parameters. To do so, each semester other/new parameters will be used to produce welds for the live discussion. The live discussion part is moderated by the assistant lecturer as depicted in figure 3.

Having the dialogue with students is the essential part of these laboratories. Figure 3 shows the application of the laboratory after performing live welding. The main lecturer asks questions, explains, and discusses the results. The assistant lecturer keeps the overview and moderates the session. This pillar is successfully passed when students upload their protocols and pass an online test.

Pillar 3: On-site presence laboratories

The on-site presence laboratory is concepted to allow students to do virtual and real welding on their own and experience topics like safety, machinery, and handling. It is to notice the weight of the torch to understand how to set parameters and to understand that the quality of a weld is very dependent on the mood, fatigue state and so on of the welder. These laboratories represent a further development of the classic laboratories. Since the classic laboratories were appreciated by students, it was decided to keep on-site laboratories in a way that students enter and start welding after a short introduction on how to use the machines. These laboratories have a working load of two hours. The past on-site presence laboratories allowed the students only to do Manual Metal Arc (MMA) welding. The newly developed concept expands not only the time students can practically weld on their own, but also give them the experience to do Metal Shielding Gas (MSG) welding as well. The new concept that also considered suggestions of the students, was applied in winter semester 2021 and summer semester 2022 to students of the module joining technology, enabling the authors to present first experiences from student and teacher perspective.

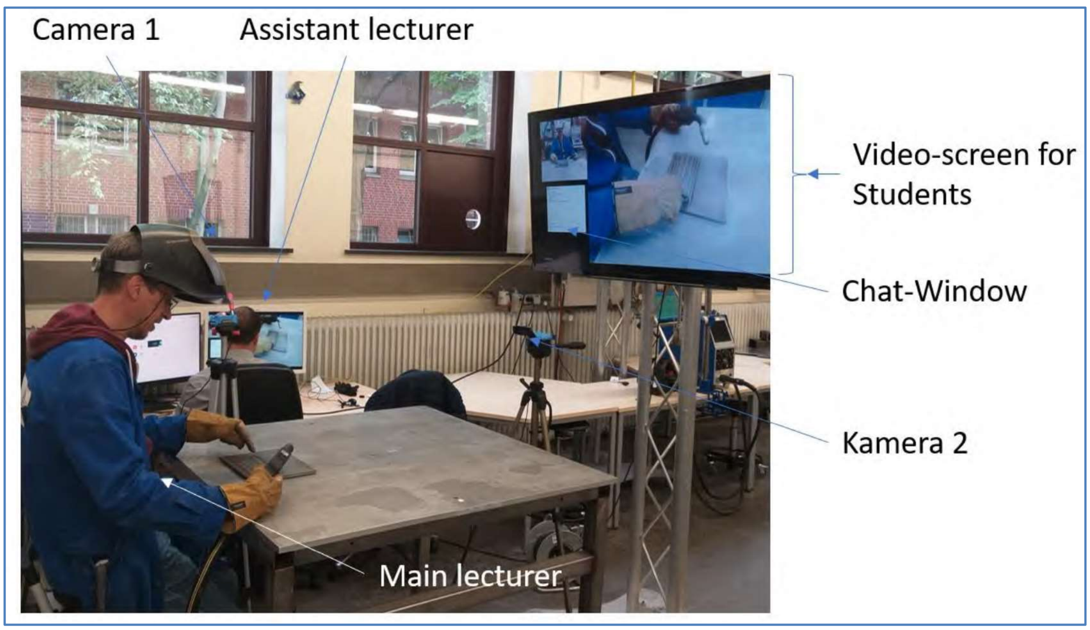

Figure 3: Schematic set up of a welding laboratory

Overall, the development of this concepts requires substantial effort prior to the course and must be started at least half a year before implementation. During the course, however, teaching effort is reduced by ca 60% over the course of the semester compared to the prior set up. This is mainly because the need to repeat a large amount of the content for three groups was reduced to only one group. Further, the virtual laboratories - though effort intensive in their development - require little to no teaching effort during the course. The implementation of the online presence laboratories takes about twice the time, as two employees are needed for the actual demonstration and operating the computer, cameras, and chat. The workload for the on-site presence laboratories remains about the same as in the previous format.

METHOD

As the purpose of this study is to present the design and evaluation of a blended laboratory, a case study approach (Yin, 1994), was employed. A case study is a research method that involves an in-depth examination of a specific situation or event, such as a person, group, organization, community, or phenomenon. It is a way of gaining insights into complex social and behavioral phenomena by studying them in their natural setting. Case studies are an appropriate research method when the goal is to understand how or why a phenomenon occurs in a particular context. It can involve the collection of data through various methods such as interviews, observations, and document analysis, and the data is usually analyzed in a holistic and interpretive manner (Merriam, 1998).

In this study, the authors collected quantitative and qualitative data from students through end of course evaluations that asked students to rate their understanding of the material and their satisfaction with the instruction, performance data in form of exam results. The quantitative data was analyzed using descriptive statistics (e.g., Cleff, 2019). The data from the teacher reflections and student evaluations were analyzed via inductive thematic analysis (Braun and Clarke, 2012) to identify patterns and common themes in the feedback as well as areas of strengths and weaknesses of the new laboratory design. Together, the data was interpreted to identify areas of improvement for instruction and assessment, and to develop recommendations for future instruction.

RESULTS

Student activity

The joining technology module consists of 3 hours lectures per week and one hour laboratory work. Thus, for the whole term, 18 hours of laboratory work must be completed by the students. Compared to traditional laboratories (before 2019) the practical time of self-welding was doubled. The theoretical part of the laboratories was converted into self-study. This way students were enabled to intensify more time for demonstration experiments and discussion with laboratory staff as well as gaining self-welding experience (see Figure 4). However, in practice, the hoped-for active participation in the online live laboratories did not materialize, as most of students were logged in but did not participate in the chat.

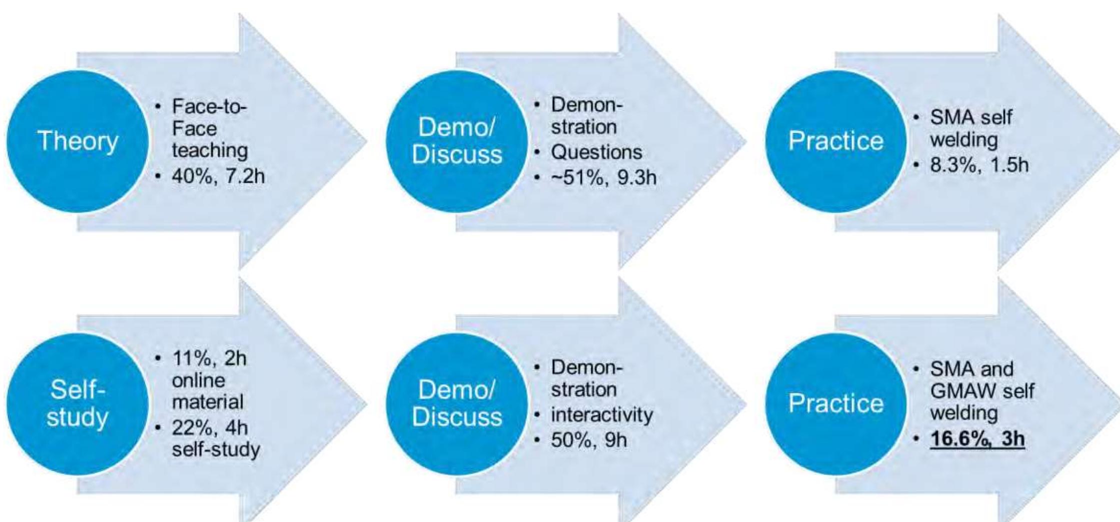

Figure 4: Conventional laboratory activities (top) compared to the new design (bottom)

Student performance

The assessment showed an overall improvement in the grades in the laboratory tests after the practice lab, which is shown in Table 1. The average grade improved from 2.3 to 1.7 (note that in the German grading system, lower grades indicate better learner performance, and it ranges from 1: very good to 5: failed). This is an improvement by 12% compared to the traditional laboratory.

Table 1. Graded laboratory test results

Semester	Number of students	Average grade
Summer 2019	71	~ 2.3
Summer 2021	66	~ 1.7

Student satisfaction

Student feedback on the new developed set-up is overall very good as indicated by the average agreements to statements about various aspects of the course design (see Figure 5). All items scored, in average, above 4 which confirms the attractiveness of the new learning design for most students. The benefits of this new learning design were also highlighted by students through qualitative feedback, with several key themes emerging. One of the most commonly mentioned benefits was the ability to participate in laboratory activities from the comfort of their own homes. This was seen as a major advantage, as it allowed students to engage in practical welding activities without the need for physical attendance at the university. Additionally, students noted the high video and streaming quality of the online resources, which improved their overall learning experience. Another benefit that was frequently mentioned by students was the improved opportunities for discussion and collaboration. The online format allowed for deeper and more technical and valuable discussions, as well as more time for self-welding and practical welding activities. Additionally, the lab-on-demand videos were always accessible, which increased flexibility in terms of time and location for students.

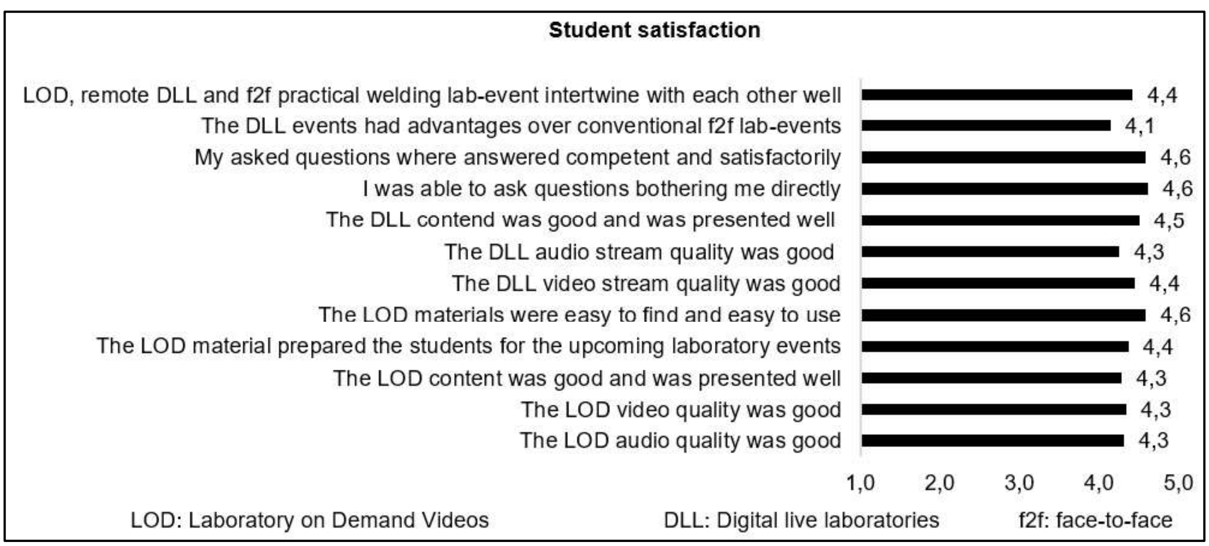

Figure 5. Student satisfaction with the new laboratory design (1…fully disagree – 5 fully agree)

However, it is important to note that the new learning design also had some drawbacks. Some students reported minor technical client site problems, such as poor internet connections, which hindered their ability to access the online resources. Additionally, some students felt that the lack of "just in time" possibility to ask questions during the lab-on-demand part was a disadvantage. The online format also made it challenging to build a sense of community among students. Finally, a part of the students also stressed the importance of using subtitles in addition to spoken explanations, to helped understand the content more easily.

DISCUSSION

This study was set out to describe and evaluate the shift towards a new learning design for laboratories in welding that utilizes educational technology and a flipped classroom pedagogy. From the student assessment and evaluation, we see that an improvement of learning outcomes was achieved, which we attribute to several factors. First, the larger amount of practice time implied an increase in active learning for the students. The students learned practical welding skills in both MSG and MMA welding which was also really appreciated by the students. Further, quality, flexibility and accessibility of the lectures and demonstrations were increased. The asynchronously provided theoretical content for self-study can be accessed and practiced by the students at their own discretion and pace. The students learned theoretical basics of welding and cutting technologies and processes which were shown by the lecturers in the online live laboratory events so students were not only told the knowledge, but they were also given examples to look at, to hear the processes and to discuss. All laboratories were recorded, and the results were made available to the students, making recapping of the content easier. The online presence laboratories showed individual welding characteristics, where the conveyance of the course content was not negatively influenced by the development of smoke gases, the noise level, or the number of group participants. Together, this set-up provided students with a better learning experience, which is also demonstrated by the evaluation results, stating that students prefer Digital Live Laboratories format over the traditional format (score 4.1). This is a somewhat surprising as students, while acknowledging the benefits of online learning, generally tend to prefer the “real thing” (e.g. Olesen et al., 2022).

There were, however, also a number of barriers that need to be addressed in the future. First, as typical for flipped learning designs, the asynchronous self-study part puts high demands on the students’ self-organization and self-regulation of learning (Stöhr et al., 2020), which was not the case for all students. Further, it is more difficult in an online setup to engage students actively via chat and the inadequate active participation of the students can frustrate the instructor. This can be explained by the increased transactional distance as the “*psychological and communication space to be crossed, a space for potential misunderstanding between the inputs of instructor and those of the learner*” (Moore, 1993, 22), compared to in-class teaching and which require measures to overcome in online learning (see Stöhr et al., 2020). Further, from a teacher perspective, the special condition of welding made it difficult for the lecturer to provide digital content. Creating those contents was a time-consuming effort and required suitable equipment that mostly was not available at first but is crucial for the success of the online learning experience. This was demonstrated through the issues with the first developed videos that had poor sound and picture quality. As a result, students did not watch the videos and both students and the teacher became frustrated. Thus, it is important to obtain the suitable equipment (cameras and microphones) beforehand and to carry out appropriate test recordings with smaller groups of students. This also implies proper training for instructors to be able to use “new” media that they have no prior experience with.

CONCLUSIONS

In recent years, the use of technology in education has been on the rise, with an increasing number of universities and institutions turning to online and blended learning methods to enhance the student experience. One such example is the implementation of a new learning design in a welding course in higher education, which utilized online resources such as laboratory simulations and lab-on-demand videos to supplement traditional in-person laboratory sessions to overcome drawbacks of traditional laboratory welding practice, where students and instructors are confronted with challenges due to smoke gases, sparks, obstructed vision, noise and acoustics etc. Overall, the new learning design implemented in the welding course at the university demonstrated a number of benefits, such as increased flexibility and improved opportunities for discussion and collaboration. However, it is also important to note that there were some drawbacks, such as technical difficulties and challenges in building a sense of community among students. The authors conclude that replacement of laboratories solely with digital content is not expedient for joining technology. Providing the videos or animations does not replace the dialogues with the instructors. In addition, it is important that particularly in the case of dangerous production activities such as welding technology, the students themselves develop a feeling for the dangers (smoke, radiation, noise, combustion, etc.) as well as for the job stress on employees (welders). This experience can only be conveyed through presence laboratories. The concept tested here shows a balanced mixture of digital events and laboratories in presence with positive results with regard to student satisfaction and learning. In the future, more contents for the virtual laboratories will be produced. Furthermore, a new method has to be developed to increase the active participation of the students. While our study provides some initial insights, further comparative research is needed to confirm the transferability of our findings to other programs and learning contexts. This may include meta-studies and comparisons of multiple single-case studies.

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