LEARNING MECHATRONICS USING DIGITAL LIVE LABS

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ABSTRACT

Practical skills training in laboratories are important elements and learning outcomes in engineering education, where leaners, through exploration, experimentation and reflection engage in inquiry-based learning that stimulate the acquisition of deep conceptual domain knowledge and inquiry skills. Traditional lab environments are very costly to maintain, partly unsafe and often require proximity of instructors and/or students that is in conflict with the Covid-19-driven need for physical/social distancing. In this paper, we describe and evaluate a course in logic control that used online labs both in pure online and in hybrid format. Students reported very high satisfaction with all three formats and achieved similar learning performances. However, qualitative analyses indicate that student learning is deeper and more authentic in the on-campus and hybrid formats compared to the pure online format. Teacher reflections show an overall positive impression of online labs. In conclusion, we recommend the hybrid format as it combines the benefits of online and physical labs, i.e., the flexibility of online laboratory work and realism of hands-on physical laboratory work.

KEYWORDS

Online learning, Online labs, Digital live labs, Hybrid teaching, Logic control, Standards 5, 6, 8

INTRODUCTION

Laboratory work are key elements in engineering education providing students with opportunities for enhancing understanding of theories and concepts as well as preparing them for engineering profession tasks such as, experimentation, and testing (e.g., Hofstein & Lunetta, 2004). Physical labs have obvious benefits for learning but also drawbacks as they are expensive, have limited accessibility and potential safety concerns. New technology offers new possibilities to arrange laboratory learning activities in hybrid or in online formats with opportunities to participate from distance. However, the effects on students' experiences and learning using online and hybrid labs are not fully understood and there is a need for learning design recommendations.

In this study we contribute to close this gap by examining a course in logic control at Chalmers University of Technology. The project-based course has recently been delivered in three different formats: campus, online and hybrid. Data on student learning, satisfaction, and experienced workload together with teacher reflections are used for comparative analyses of the three formats.

CONTEXT: THE LOGIC CONTROL COURSE

The 7.5 ECTS course named “Logic Control” (Chalmers University of Technology, 2021) is given as a project-based course at the end of the first year of the BSc programs in Electrical Engineering and Mechatronics Engineering for a total of 100 students. The intended learning outcomes include programming of an industrial PLC (Programmable Logic Controller) system, programming of a microcontroller and to use electronic components for communication between the two control systems.

The students work in pairs to solve one of three similarly complex project tasks, where PLC programming, programming of a microcontroller and use of electronic components are trained. They have studied courses in computer engineering (including Boolean algebra), electric circuits and programming in C during their first year. This knowledge from previous courses is needed in the projects. The course adds new information through seven two-hour lectures early in the course. The course literature consists of two compendia, manuals, and datasheets.

Assessment of the student knowledge and skills is done in four parts: solved project task, written report, individual short written test, and oral presentation of the project. The oral presentation includes individual questions to test the understanding of fundamental parts of the course.

During the years 2019 – 2021, the course has been given three times in three different formats. In 2019, and the years before, on-campus formats were used. In 2020, the course was given in pure online format and in 2021 in hybrid format.

STATE-OF-THE ART

Online labs have been examined as a viable alternative to physical labs, where the benefits - realistic data, the interaction with real equipment and the opportunity to collaborate and interact with other students and the teacher – stand against the high costs, time, and place restrictions as well as scheduling and supervision requirements (Nedic et al., 2003). The literature generally distinguishes two types of online laboratories – virtual and remote (Chen et al., 2010). Virtual laboratories refer to simulated lab environments based on software such as Matlab/Simulink, LabView, Java Applets or others. Remote labs are lab experiments with real instruments and/or components that are remotely controlled with the help of the internet - either directly or via instructions to staff on site. Both types of online labs have been investigated in terms of their strengths and weaknesses and regarding their effect on student learning. Research has thereby provided case studies reporting on the design and evaluation of numerous virtual and remote lab environments of varying levels of technical complexity (e.g., Wang et al., 2015; de Jong et al., 2014; Potkonjak et al., 2016).

Several potential benefits of virtual and remote labs over traditional labs have been identified (e.g., Potkonjak et al., 2016; Chen et al., 2010; Post et al., 2019; Nedic et al., 2003; Lynch & Ghergulescu, 2017; de Jong et al., 2014). The most cited reasons to integrate both remote and virtual labs in higher education are the expected cost reduction and simplified maintenance of lab facilities, while providing students with a safe learning environment that can be accessed from anywhere. Both forms of online labs are more cost-efficient because virtual labs are easier to set up and maintain and involve comparatively low equipment costs, whereas remote labs can be used much more efficiently through tight scheduling, shorter time slots and non-stop scheduling. Access and set-up are more flexible as online labs can be available 24/7 and offer geographically distributed learners the possibility to remotely collaborate and cooperate with each other and the instructor. Remote labs allow for interaction with real equipment. Virtual labs on the other hand enable a variety of experiments with different components and changes in system configurations. Experiments can easily be repeated, and the inner mechanics of lab devices can be observed with greater transparency and without damage or impact risk. The very nature of virtual environments is also its main disadvantage – they do not actually exist which may result in a lack of real-life feel and seriousness for students that might experience virtual lab more as a game, making impactful teaching about health and safety issues difficult. Even in remote labs, students are only virtually present in the lab. Further, depending on the technology used in virtual labs there are risks of oversimplifications and a lack of natural variation – adapting virtual labs to class contexts requires advanced understanding of the underlying software. In addition, the necessary professional development of teachers to enable them to create well-designed inquiry environments can be a major challenge.

With regard to learning, Brinson (2015) in a review of 56 studies concludes that learning outcomes were equal or better from virtual or remote labs compared to traditional labs. For example, Wang et al. (2015) found that compared with traditional lab environments, the use of a virtual physics lab provided students with more in-depth practice of process skills, comprehensive skills, and reflection skills of scientific inquiry. In another review paper focusing on learning outcomes of remote labs, Post et al. (2019) found positive results with respect to gain of conceptual knowledge, student engagement and student satisfaction. However, they also argue that the review of learning outcomes was superficial as most articles do not focus on that aspect and more research is needed in that regard. Similarly, Potkonjak et al. (2016) point at the fact that most online labs are adapted to a specific educational context with very limited degrees of generalizability. On a more critical note, some authors point at the need to improve learning in online labs through more careful design and the coordination of group and individual activities (Corter et al., 2011). Others argue that online labs - while providing value to education – should and cannot replace traditional lab environments completely and its usage should be governed by the teaching goals balancing the simplicity and physical experience of the student with the appeal and convenience of digital learning environments (e.g., Scheckler, 2003; Sicker et al., 2005).

Some authors have suggested to overcome some of the drawbacks of simulations and remote labs by combining both into hybrid labs (e.g., Rodriguez-Gil et al., 2017; Henke et al., 2013; Lei et al., 2018). In this format, the scalability and cost-effectiveness of virtual simulations are combined with the higher authenticity of remote labs. While being relatively new, tentative evidence suggests that this format is interesting and engaging to the students and has educational potential (Rodriguez-Gil et al., 2017). Little attention has been paid to combinations of online and real lab sessions. This learning design attempts to provide students with the flexibility of remote or virtual labs as well as the real-world hands-on experiences (Zhu, 2010). A recent study in chemistry (Enneking et al., 2019) reported that compared to traditional labs, this format provided similar results regarding the students' cognitive and psychomotor development. On the other hand, students were less able to see real-world connections and spend less time reflecting upon the underlying concepts.

In sum, we conclude that while there is increasing evidence that virtual and remote labs can effectively replace physical labs at least in part, the mixed results point to the importance of adapting online learning environments to the educational context, in which the potential of hybrid solutions has been recognized but needs further exploration and validation.

THREE DIFFERENT COURSE FORMATS

The same course has been given in three different formats. All three formats had the same intended learning outcomes and students had the same preceding courses. Three of the preceding courses are considered vital for the Logic Control course but the students were eligible to take the Logic Control course without having passed these courses.

In the on-campus format, all seven lectures were given live in a classroom and the students were provided with pdfs of the lecture notes. All project work was conducted in labs with physical equipment for direct testing and trouble shooting. The students had each 48 hours scheduled in the lab for their project work, more if needed. The scheduled lab time was mandatory to attend until the project was finished. Assessment of the solved project task was done in the lab, by presenting the solution to the teacher.

In the pure online format, the three PLC lectures were given as short, pre-recorded films. The scheduled online lecture sessions were used for a short overview and time for discussion and questions about the films. The three lectures on microcontroller and the lecture on electrical components and troubleshooting were given live online. All lectures were recorded and were made available to the students after the lecture. All project work was conducted at home in simulation models and the groups had 48 hours online to ask questions. Each week, the groups had to send in a progress report and their code. The teachers read the progress reports, answered unsolved questions, and gave a few comments on the code. Assessment of the solved project task was done online at two 30 minutes sessions per group.

In the hybrid format, all lectures were given online, and the structure of the lectures was maintained from the online format. The students were given 24 scheduled hours in the lab for their project work. The scheduled lab time was mandatory to attend until the project was finished. The students had the possibility to attend 8 hours of the mandatory lab time remotely. They were provided with simulation models for preparation at home and 20 hours of online sessions for questions between the scheduled times in the lab. Assessment of the solved project task was done in the lab, by presenting the solution to the teacher.

THE DIGITAL LIVE LAB SETUP (ONLINE AND HYBRID)

In both the pure online format and the hybrid format, the students had to prepare and work outside of the scheduled lab hours. The preparations were made using simulation models.

For the PLC part, a simulation model of the physical system was developed in the PLC programming environment Codesys. The program code can be tested in the simulated environment on a PC and transferred to the PLC systems in the lab. Codesys is free of charge and can be downloaded to any PC with a Windows operating system (Codesys, 2022).

The microcontroller used was a PIC processor in the on-campus format and in the pure online format. For the hybrid format, the microcontroller was changed to the developing platform Arduino Uno. The PIC processor can be programmed and simulated in MPLABX (MPLABX, 2022), which is free of charge and can be downloaded to any PC and any operating system.

The Arduino Uno and electrical components can be simulated in the web-based program Tinkercad (Tinkercad, 2022).

The hybrid learning set-ups were guided by the pandemic restrictions, i.e., the maximum students in rooms, and the need for students to stay at home when experiencing symptoms. In the hybrid format it was possible for both students in a pair to be on campus for the labs, and it was possible for one student to be on campus and the other student to be online and work together. An example of the setup for one student online is seen in Figure 1. The setup facilitated one web camera (encircled in yellow) and one conference mic (encircled in red). The students were communicating online through Zoom, where the student in the lab could share the screen and give control to the other student. Through the conference microphone, the teacher could talk to and discuss with both students at the same time, as if they were both in the lab.

Figure 1. Lab setup for lab session with one student on campus and one student online in hybrid format. The web camera is marked in yellow, and the conference mic is marked in red.

For the pure online format, the assessment of the function was conducted in two steps. The first function test was made halfway through the project, when the students had made most of the PLC code and had started to connect the PLC system to the microcontroller system. This first test was made for the students to gain a better understanding of the total project and to check their understanding. The second test was a function test of the entire system. In both tests, one teacher was in the lab with the physical equipment and the students participated through Zoom. The lab setup for the function tests is seen in Figure 2. One web camera (encircled in yellow) and a headset for the teacher were used. All communication was through Zoom, where the teacher could share the screen.

Before the function tests, the students had to submit their code and their circuit diagram schematics. The teacher had prepared some of the circuits on a breadboard. The teacher had checked that the schematics resembled the prepared breadboard circuits and checked that the programs could work with some minor adjustments. If the criteria for preparations were not met, the students had to make changes and resubmit for the function test.

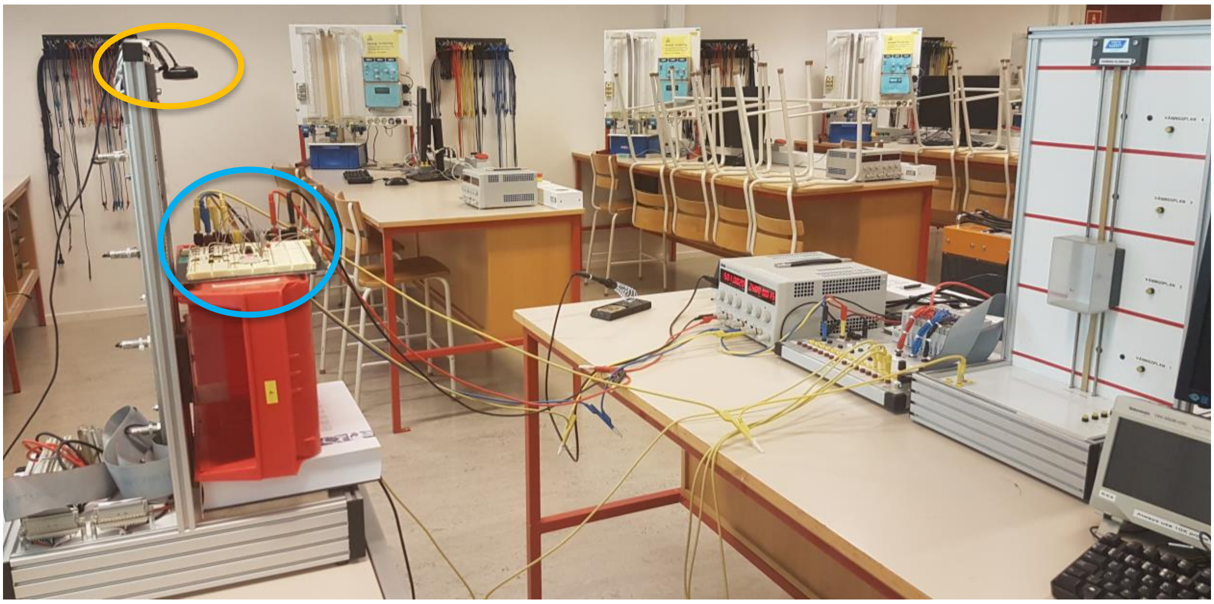

Figure 2. Lab setup for function test in the case of pure online format. The web camera is marked in yellow and can be angled to show the breadboard, marked in blue or the controlled system

During the test, the teacher showed the prepared breadboard and asked the students about the components, and where to connect about eight missing wires. Figure 2 shows the web camera encircled in yellow and angled to show the breadboard, that is marked in blue. The teacher showed the download of the code to the PLC and the microcontroller and made function tests from the students' instructions.

In order to pass the function test, the students needed to prove that their programs and designs worked, and that the hardware could be controlled to specifications. They also needed to answer questions about the electric components and their programs. The questions served the purpose of ensuring that both students had been working with the preparations and had understood what they had done. The discussion also gave an opportunity to sort out any misunderstandings.

RESEARCH METHOD

This is a comparative case study based on three different course formats (on-campus 51 students, on-line 62 students, and hybrid 46 students). Data was collected from:

- student throughput data,
- end-of-course evaluation questionnaire, and
- teacher observations and reflections.

Quantitative comparisons have been made of student throughput, student satisfaction ratings and self-reported student workload. We used standard statistical test procedures for determining the significance of the observed differences, namely one-sample t-tests for comparing observed course means with the program averages and one-way ANOVA for comparing the course formats with each other (e.g., Acton et al., 2009).

As a follow up analysis, we also analyzed the effect of student participation in preceding courses on their likelihood to pass this course as a controlling factor. We used binary logistic regression (e.g., Bewick et al. 2005) with the number of completed preceding courses (between none and three) as regressor variable. The predictor variable, *number of passed preceding courses*, was tested a priori to verify there was no violation of the assumption of the linearity of the logit. The output analyses involved the Wald test at a 95% level of significance. The model's reliability was verified by analyses of chi-square omnibus, Nagelkerke R^2, and Hosmer and Lemeshow tests (Cleff, 2019).

Finally, qualitative analyses have been made based on teacher reflections and student free-text comments from end-of-course evaluation questionnaires, using inductive thematic analysis (Braun and Clarke, 2012).

RESULTS

Student throughput

As outlined in Table A1 (see Appendix A), the student throughput was approximately the same in the on-campus format (75%) as in the pure online format (74%). However, in the hybrid format, the throughput had decreased to 67%. An one way analysis of variance (ANOVA) showed nevertheless that the difference between course formats regarding student throughput was not significant, F(2,156) = .389, p = .678 (see Table A2). Further, the average student throughput for all courses in the two programs is 77%. None of the three course formats differs significantly from that (see Table A3).

As a controlling factor, we also studied the student throughput in preceding courses, where the same decrease for students in the hybrid format was observed. Figure 3 shows the correlation between passing the Logic Control course and the three preceding courses: Introduction to Computer Engineering, Electrical Circuits, and Programming in C. The coloring goes from dark blue for passing all three preceding courses to white for not passing any of the three preceding courses. Figure 3 illustrates that passing all three preceding courses gives a high probability of passing the Logic Control course. Almost everyone who passed the three preceding courses also passed the Logic Control course regardless of the format. Furthermore, the figure shows that not passing any of the preceding courses gives a low likelihood of passing the course in Logic Control. Hence, the lower throughput in the preceding courses is the most probable cause of the lower throughput in the Logic Control course in the hybrid format 2021.

To confirm this observed effect, a binary logistic regression analysis was conducted to investigate the relationship between the *number of passed preceding cours*es and *passing the Logic Control course*. The logistic regression model (Table A4) with only this one regressor correctly predicted 87.4% of the passing or non-passing students, with significant chi-square value (96.788, p = .000, Table A5). The Hosmer and Lemeshow test indicated the model consistency (1.964, p = .375, Table A6), and the Nagelkerke R^2 performed a very good overall fit (.658, Table A7). In terms of effect size, the model shows an 'odds ratio' of 6.312 (see Table A8), which is significant (Wald = 49.487, p = .000) and suggests that with each passed preceding course, the odds of a student to belong to the passing group of the Logic Control course increases by that factor. The coefficient on the *number of passed preceding cours*es variable has a Wald statistic equal to 49.49 which is significant at the .001 level.

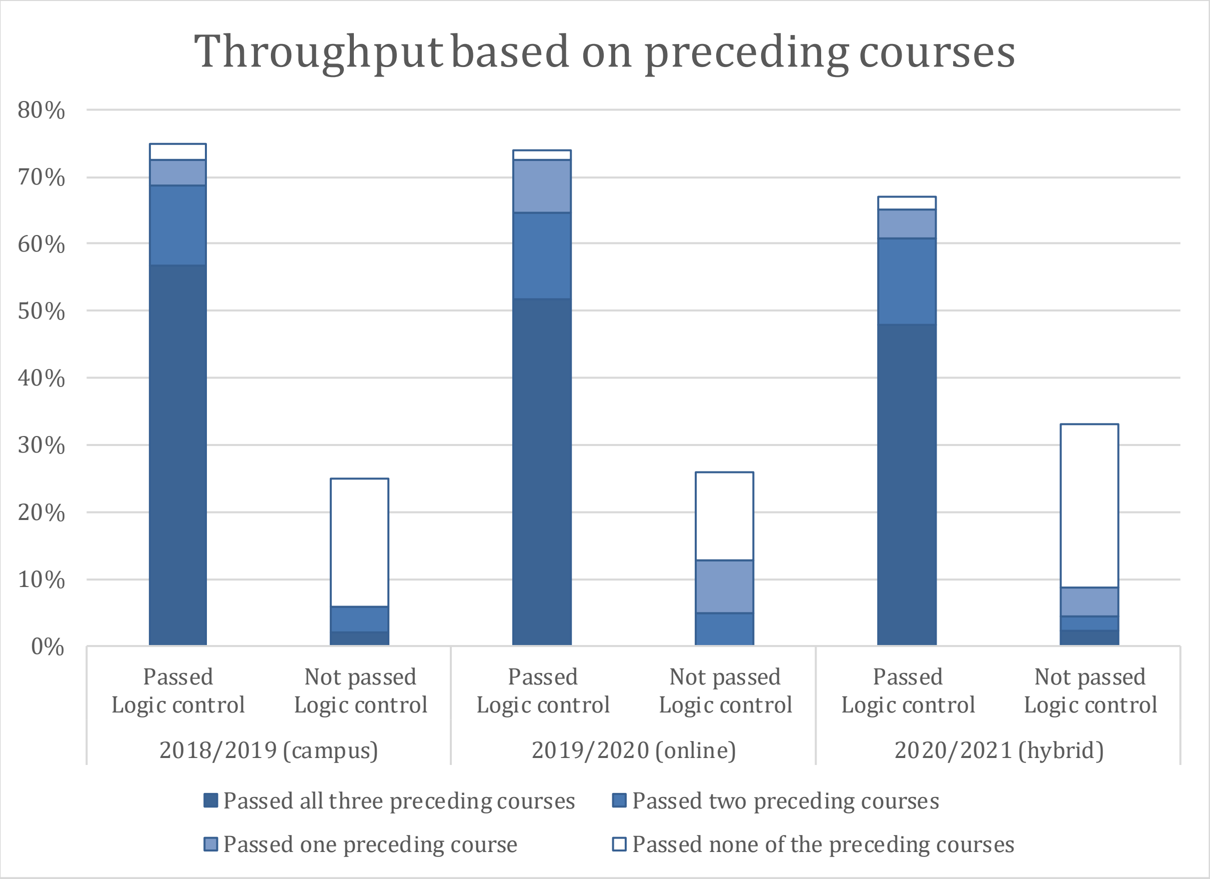

Figure 3. Throughput in the logic control course in relation to success in preceding courses

Student learning

Apart from student throughput, information about student learning is limited. The online format and the hybrid format gave the students working conditions, that can be more like the working conditions they will face as engineers. In most development projects of automation or control systems, continuous testing on the physical system is too costly. Therefore, most development and programming are tested in simulation models. Both formats also put higher demands on preparations and time management.

Some of the questionnaire answers indicate that the students gained much of their understanding of the systems in the lab, where they could see how everything was connected and worked together. In the pure online format, some students did not reach that understanding until the first function test. In both the on-campus format and hybrid format, the answers showed appreciation for the time to work in the lab.
One important step of the course is troubleshooting of the electrical circuits. For many students, that was also the most time-consuming step in the on-campus format. Troubleshooting can be trained in the simulation environment of Tinkercad but not fully. That could be observed in the hybrid format course, where students had made preparations of their circuits in Tinkercad but still had trouble to work out in their circuits on the breadboards in the lab. That more extensive troubleshooting was unfortunately not a part of the pure online course.

Student satisfaction

Course evaluations have been made each year from questionnaires and a course evaluation meeting. The student satisfaction has been high in all three formats, but slightly higher in the on-campus format (4.86 for on-campus and 4.33 for both online and hybrid, in a scale 1-5, poor to excellent, Table A9). The ANOVA did not show any significant differences between the three formats, $F(2,25) = 1.562$, $p = .229$ (see Table A10).

The average student satisfaction for all courses in the two programs is 3.7, which is lower than in all three of the formats examined here. A one-way t-test confirms that the difference is significant for all three formats (Table A11).

Student workload

Students reported the same workload in the on-campus format as in the pure online format. However, they reported higher workload in the hybrid format. The higher workload is a consequence of working both in the simulators and the physical hardware. Several groups struggled with transferring their simulated results to the lab setup. From a teacher perspective, that is important training but from a student perspective, it takes time. Some student groups also struggled with troubleshooting the same problem twice, first in Tinkercad and then on their breadboard.

Consultation sessions were used between the lab sessions in the hybrid format to aid the students in their work. However, many students did not come to the online consultation sessions. They reported that they were working at other times and had solved their questions before the consultation sessions. Working on their own helps in learning but can increase the workload.

Teacher reflections

The teachers reported the highest workload in the pure online format. The higher workload was mostly due to the progress reports and the function tests.

From a teacher perspective, online consultation sessions are effective. One teacher can meet and guide more students in an online session than in a lab session. Using more consultation sessions, as in the hybrid format, can therefore reduce the teacher workload.

In both the pure online format and in the hybrid format, the students plan their work themselves, in contrast to the on-campus format when they could come and work at scheduled times in the lab. Most students handled the planning very well. However, the quieter students and the less motivated students had a tendency not to come to the consultation sessions, they asked fewer questions and finished their project later or not at all. As a teacher, it is easier to see and motivate these students in the lab.

The individual work of each student in a group is harder to see in an online format. Therefore, the small written test and the oral discussions at the end of the course are more important in the pure online format but also in the hybrid format. In all three formats, they are one tool for explaining the individual grading of two students in a pair.

In the pure online format, the students are guiding the teacher through their code and their electrical circuits in the function tests. The function tests are a part of the assessment of the course and meanwhile they were the only time the students could use the physical hardware. The duality of the sessions sometimes made it hard to balance between explaining and assessing the students' knowledge.

From teachers' perspective the hardware and software set-ups functioned very well and supported student learning as well as student-to-student interaction and student-teacher interaction.

DISCUSSION

This study was set out to examine student experiences and learning in a lab course conducted in three different formats. Our results confirm earlier studies in that students achieved similar throughputs in online, hybrid and traditional learning environments (e.g. Brinson, 2015; Enneking et al., 2017) and expressed high levels of satisfaction in each format (Post et al., 2019; Corter et al. 2007). The slight preference of students for the hands-on format in our results is also mirrored in other studies and has been explained with the fact that students can work with actual equipment (Post et al., 2019).

However, especially from the teacher reflections, we could also identify potential issues. As others (e.g., Potkonjak et al, 2016) we identify the transfer of knowledge from the online to the physical lab environment as something that needs to be carefully considered in the learning design. Another challenge relates to what Stöhr et al. (2020) call the "polarization effect" of online learning. While offering more flexibility, online learning environments tend to put higher demands on students' ability to regulate and organize their learning compared to campus-based education with the effect that strong students might benefit from online learning while weaker students struggle even more.

Further, in difference to earlier studies, the introduction of the pure online format and the hybrid format has been driven by the Covid-19 pandemic with potentially profound effects on delivery and student experiences in the lab environments (Gamage et al., 2020). Thus, the pandemic and some changes in the teaching staff have influenced our results. In the presented results, these influences have been filtered out as far as possible for the purpose of comparison, but some effects remain.

The short time for preparations and restrictions due to Covid-19 prevented recording of a lecture in the lab about the hardware. A lecture like that would have helped student understanding of the physical systems and how they would work together. We also needed to reduce the number of alternative projects from three to one.

A change was made in the teacher staff before the hybrid format round of the course, resulting in fewer available teacher hours. Restrictions due to the pandemic put limits on the number of students in the lab at the same time. Both these changes resulted in the lower number of hours where the students could get help from a teacher in the hybrid format. That put higher demands on the students and is one reason for the reported higher student workload. Without restrictions from the pandemic, the students can have more hours in the lab.

The change in teacher staff before the hybrid format resulted in two hand-in assignments and a change of focus in the first lab session. The addition of two hand-in assignments resulted in a higher workload for both teachers and students but also in higher student learning. The shift of the first lab session took time from the project and the students fell behind their plan early in the project. The hand-in assignments helped in understanding and will be kept but adjusted to resemble the project more. The first lab session will be shifted back to understanding the physical systems and start of the project. It will also be used to show how to ease the time-consuming transition between preparations and lab work.

Preparations between the labs have been hard and time consuming for the students. However, they are given the possibility to learn both time management and a more realistic way of working as an engineer. The simulation tools and online consultation sessions can be kept, and the job can be less time consuming for the students if they are guided through how to transfer their simulated results to the physical hardware.

The students were not allowed to bring the equipment home to prepare due to limited number of lab kits. To continue developing the on-line format to satisfy all learning outcomes it is necessary to invest in enough lab kits, so that each student can work individually with circuit set-up from home. This can also solve the problem of balancing explanation and assessment as well as providing more hands-on training.

The possibility to work from home has opened an opportunity for students to participate also with a minor illness. Furthermore, the setup can be used for collaborations between students from different universities taking the same course or lab.

CONCLUSIONS

Digital labs have been used in both a pure online format and in a hybrid format. Both formats have been compared to the same course in an on-campus format. The students in the pure online format gained less training in trouble shooting compared to the other formats and the pure online format was more time consuming from a teacher's perspective. Therefore, the pure online format is not the primary recommendation from this study.

The hybrid format on the other hand, has proven to work well. With some modifications to lower the student workload, the hybrid format can be recommended for this type of course. From a teacher's perspective, online consultation sessions are more efficient than meeting the students in the lab. The possibility to follow physical labs online if needed, provides extra flexibility in the hybrid format compared to the on-campus format. The same format can be used in collaborations between universities for both students and teachers.

An extra benefit from the hybrid format is that the students train in a more authentic set-up as engineers, where they must make preparations before testing the theories on the physical system.

This study has focused on one specific course and some of the positive effects of the hybrid format may be limited to labs that show similarities to this course. The use of simulation model has been crucial to the digital labs. Following physical labs online is likely to work better if much of the lab is by use of a computer and observations of the physical systems, in contrast to labs where hands-on operation of the equipment is a vital part.

As many other studies, this has been a single-case study. To gain more insight in the area, meta studies and comparison of all single-case studies are needed.

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APPENDIX A

Table A1. Descriptive statistics for student throughput for on-campus, online and hybrid format

	N	Mean	Std. Deviation	Std. Error
On-campus	51	.75	.440	.062
Online	62	.74	.441	.056
Hybrid	46	.67	.474	.070

Table A2. ANOVA comparing student throughput in on-campus, online and hybrid format

	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	.158	2	.079	.389	.678
Within Groups	31.666	156	.203		
Total	31.824	158			

Table A3. One sample t-test of student throughput in on-campus, online and hybrid format versus the program average of 77%

	Test Value = .77					
					95% Confidence Interval of the Difference	
Format	t	df	Sig. (2-tailed)	Mean Difference	Lower	Upper
Hybrid	-1.375	45	.176	-.096	-.24	.04
On campus	-.404	50	.688	-.025	-.15	.10
Online	-.501	61	.618	-.028	-.14	.08

Table A4: Classification Table[a]

			Predicted		
			Pass		Percentage Correct
	Observed		0	1	
Step 1	Pass	0	36	8	81.8
		1	12	103	89.6
	Overall Percentage				87.4

a. The cut value is .500

Table A5: Omnibus Tests of Model Coefficients

		Chi-square	df	Sig.
Step 1	Step	96.788	1	.000
	Block	96.788	1	.000
	Model	96.788	1	.000

Table A6: Hosmer and Lemeshow Test

Step	Chi-square	df	Sig.
1	1.964	2	.375

Table A7: Model Summary

Step	-2 Log likelihood	Cox & Snell R Square	Nagelkerke R Square
1	90.780[a]	.456	.658

a. Estimation terminated at iteration number 6 because parameter estimates changed by less than .001.

Table A8: Variables in the equation

Variables in the Equation

		B	S.E.	Wald	df	Sig.	Exp(B)	95% C.I.for EXP(B)	
								Lower	Upper
Step 1[a]	Number of preceding courses	1.842	.262	49.487	1	.000	6.312	3.778	10.545
	Constant	-2.052	.458	20.056	1	.000	.128		

a. Variable(s) entered on step 1: Number of preceding courses.

Table A9: Descriptive statistics for student satisfaction for on-campus, online and hybrid format

Format	N	Mean	Std. Deviation	Std. Error
Hybrid	12	4.33	.778	.225
On campus	7	4.86	.378	.143
Online	9	4.33	.707	.236

Table A10. ANOVA comparing student satisfaction in on-campus, online and hybrid format

	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	1.440	2	.720	1.562	.229
Within Groups	11.524	25	.461		
Total	12.964	27			

Table A11. One sample t-test of student satisfaction in on-campus, online and hybrid format versus the program average of 3.7

	Test Value = 3.7					
					95% Confidence Interval of the Difference	
Format	t	df	Sig. (2-tailed)	Mean Difference	Lower	Upper
Hybrid	2.818	11	.017	.633	.14	1.13
On campus	8.100	6	.000	1.157	.81	1.51
Online	2.687	8	.028	.633	.09	1.18

BIOGRAPHICAL INFORMATION

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