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Lab courses for prospective physics teachers: what could we learn from the first COVID-19 lockdown?

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Abstract

At the universities of Dresden, Vienna, and Zagreb, a laboratory course for prospective physics teachers was transferred to an online environment because of the lockdown in March 2020 due to the COVID-19 pandemic. The aim of this paper is to present and compare students' and instructors' considerations about the experiences with this laboratory course at these three universities and to formulate guidelines for organizing lab courses for prospective physics teachers. The research was conducted in three steps: first, interviews were conducted with prospective physics teachers ($N = 10$); second, an online questionnaire was administered to course participants ($N = 99$); and third, lab course instructors completed an online questionnaire ($N = 8$). The results show that an increase in *creativity* and *confidence* was expressed when conducting home experiments. Students who received *support and guidance* benefited more from the online

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lab course, but some students also experienced a greater *time commitment*. On a positive note, all participants thought outside-the-box during this lab experience and found solutions that led to new ways of conducting labs. Our study suggests that in future online or regular lab courses, students should have the chance to make decisions about experiments and be creative, with an emphasis on peer discussions and support from instructors.

Keywords: COVID-19 lockdown, physics education, university education

 Supplementary material for this article is available [online](#)

(Some figures may appear in colour only in the online journal)

1. Introduction

As part of becoming physics teachers, students must gain physics content knowledge, which is done through regular physics classes where they learn physical concepts and laws. They also need to learn pedagogical knowledge: how a child's brain works and develops over the years, how children learn, work with others and how a teacher can manage and work in a classroom. This is usually covered in several psychology and pedagogy courses. Most importantly, prospective physics teachers need to master pedagogical content knowledge (PCK) which combines physics content knowledge with pedagogical knowledge to create a specific understanding of ideas about physics, the difficulties students could have with these ideas, teaching strategies they can implement, and problems they could encounter [1]. Students learn and develop PCK during different courses, such as laboratory exercises for prospective physics teachers, physics education, school practice etc.

In the lab courses for prospective physics teachers, students learn to design, prepare, and perform school experiments by combining PCK and experimental skills with interactive teaching techniques. The objectives for the specific courses at the three universities rely on the objectives of experimental work for prospective physics teachers given by Nivalainen *et al* [2]. They are:

- Developing practical and experimental skills.
- Developing an understanding of science content and conceptual understanding.
- Fostering motivation.
- Developing an understanding of the nature of science and of scientific process.
- Enhancing social and learning skills.

The focus of this paper is on the impact the prospective physics teachers faced during the COVID-19 lockdown in spring 2020 at the several authors' universities (hereafter pseudonymized randomly as Universities A, B, and C) with respect to their education in a major PCK course: *Laboratory for prospective physics teachers*.

The first COVID-19 lockdown in Austria, Croatia, and Germany started at the end of March 2020. Prior to this, there was no experience with online university courses for prospective physics teachers at the authors' universities. Online classes are not new to the science education community [3–8], but without any experience with online classes at the three universities, it was a challenge to design an online course such as the laboratory for prospective teachers within a few weeks. We consider the online classes as classes where the activities that are usually conducted at university are transferred to a virtual room, either as synchronous format

where the students and the instructor are online at a same time or as an asynchronous format, where the online materials are provided via learning platforms or e-mails and students work at their own pace. In our previously published paper [9], we found that the most common transformation of standard physics laboratory courses (designed for prospective physicists or engineers) at the authors' universities included doing online work using either simulations or videos of real experiments and extracting data from them.

Three different online formats used for the lab course for prospective physics teachers are compared within this paper. The goal is to formulate guidelines for instructors of lab courses for prospective physics teachers based on what was learnt from the lockdown reorganization. This study aims to do so by answering the following research question *what were the experiences of students and instructors with online laboratory courses for prospective physics teachers during the first COVID-19 lockdown?*

2. Lab courses for prospective physics teachers during the covid-19 lockdown

During the strict lockdown, students were not allowed to attend classes at the three surveyed universities, and courses were organized online. At the end of the summer semester 2020, only at University A, a few at-faculty lab lessons were organized.

Unfortunately, to our knowledge, no research about online formats of laboratory courses for prospective physics teachers could be found. However, a few university instructors who encountered standard laboratory course lockdown challenges reported on their experiences in detail [10–13]. Bradbury and Pols [12] reported on using an open-inquiry laboratory form and flipped-classroom approach with the aim of teaching scientific inquiry. They created a pandemic resilient lab course. Students were required to design their own experiments and conduct them at home, while videoconferences were used to support and discuss students' projects. A similar reorganization was done for the laboratory course for prospective teachers at University C. At Delft University of Technology [11], the first-year physics lab course also switched to an online format and was reorganized to focus more on inquiry-based experiments than guided ones which are usually performed at the university. This helped them to unveil students' shortcomings while carrying out the experiment, such as quickly moving to data collection without considering the quality of the collected data.

All these transformations had some positive and negative effects on the students' and instructors' workload and time management. Hut *et al* [10] reported that the instructors' workload tripled in size because they needed to provide feedback to each student when grading home projects in a transformed workshop-like course for freshman physics students. They also reported that students worked overtime on their projects from home, which resulted in less time for other courses and obligations. Positively, Fox *et al* [13] concluded that all lockdown changes to their lab course for first-year students did not significantly affect student views and epistemologies about experimental physics. From our point of view, that is an optimistic outcome since a lot of instructors are worried about negative lockdown consequences for both students and themselves.

Figure 1 provides a brief comparison of the restructuring of the lab courses for an online environment. The advantage of these specific lab courses was that school experiments are often simple, requiring minimal equipment, and thus, students were able to perform some of them at home. Also, when experiments with more sophisticated equipment were included, instructors resorted to simulations or filmed experiments. For example, demonstrating the photoelectric effect is not a suitable home experiment, so instructors at University B filmed the experiment

	University A	University B	University C
Lab assignments	Adapted tasks: home experiments, simulations, and filmed experiments were suggested		Tasks from the regular lab course, added with the request to perform the experiments at home (or to use simulations if this is not possible)
Video conference with instructor and small students' group	<ul style="list-style-type: none"> • After conducting the home experiments • Discussing solutions, questions, problems, ideas • Oral feedback to submitted students' reports 		<ul style="list-style-type: none"> • Before conducting the experiments • Gathering and discussing ideas for home experiments fulfilling the tasks
Compulsory elements	Conducting three experiments that are the focus of the final report (one topic was chosen, for instance wave optics)	Attendance in videoconferences	
		Submission of lab reports via e-mail	Submission of lab reports via learning platform, verifying the conduction of the experiments by images or videos
Final grade	Written final report of one topic	Written online-exam and submitted lab reports	Online pre-lab quizzes and submitted lab reports

Figure 1. Comparison of adapted lab courses for prospective physics teachers between different universities during the first 2020 lockdown.

that can be performed in schools and then also gave a simulation that allowed students to further explore the photoelectric effect.

3. Methodology

3.1. Research design and data collection

Figure 2 shows our research design and the number of participants. All students of online laboratory courses from three universities were invited to participate in the interviews and questionnaire via e-mail either by the course instructors or the faculty dean. The participants were conveniently sampled. It is a non-probability sampling and consists of choosing participants based on their convenience [14].

Initially, the research ideas and data about impacts of the COVID-19 lockdown on students' attendance, work, and learning were collected by interviews (supplement A)

	Students' experiences		Instructors' experiences
	I Interviews 04-05/2020	II Questionnaire 06-08/2020	III Questionnaire 08-09/2020
Kind of research	qualitative	quantitative	qualitative
Instruments (See Supplement A)	<ul style="list-style-type: none"> • Online interviews (using Zoom or BigBlueButton) • Lasting 45-75 minutes • In native language (German or Croatian) 	<ul style="list-style-type: none"> • Online questionnaire (using Unipark Questback) • 14 items regarding lab course • In native language (German or Croatian) 	<ul style="list-style-type: none"> • Online, open ended questionnaire (anonymous uploading in a cloud) • In English or German
Participants Conveniently sampled, neither rewarded for their participation nor penalized for not participating	10 prospective physics teachers	99 prospective physics teachers (*Percentage of all course participants)	8 instructors of lab courses
University A	3	28 (*43%)	4
University B	3	31 (*65%)	0
University C	4	40 (*57%)	4

Figure 2. Research design and number of participants per university.

(<https://stacks.iop.org/EJP/43/055701/mmedia>). These qualitative findings were then used to formulate research questions for the quantitative research and helped us to design a questionnaire that was distributed to a wider population of students [15]. In this paper, we report on the lab courses for prospective teachers which took place at the universities of Dresden, Vienna, and Zagreb during the semester of the first lockdown. Other parts of our study are reported in [9], and another manuscript on students' experiences with various online course formats and perceptions of its helpfulness is currently in preparation.

Additionally, results from the interviews were also used to formulate an open-ended questionnaire for instructors of the laboratory course for prospective physics teachers (supplement A). Only instructors from Universities A and C participated. University B was excluded from participation since one of the authors was leading the course and anonymity of the instructors could not be guaranteed.

This study was carried out in accordance with the principles outlined in the Statutes for Ensuring Good Scientific Practice of University of Dresden [16], in the Mission Statement [17] and Statutes of the University of Vienna [18], and in the Ethical Codex of University of Zagreb [19]. In addition, all participants were volunteers and were informed about the research process and requirements, both verbally and in writing, and an informed consent was obtained from them.

3.2. Data analysis

Interviews were transcribed and analysed in its original language (Croatian or German) to avoid translation inaccuracies. Any ambiguities were double-checked by the researcher, who is

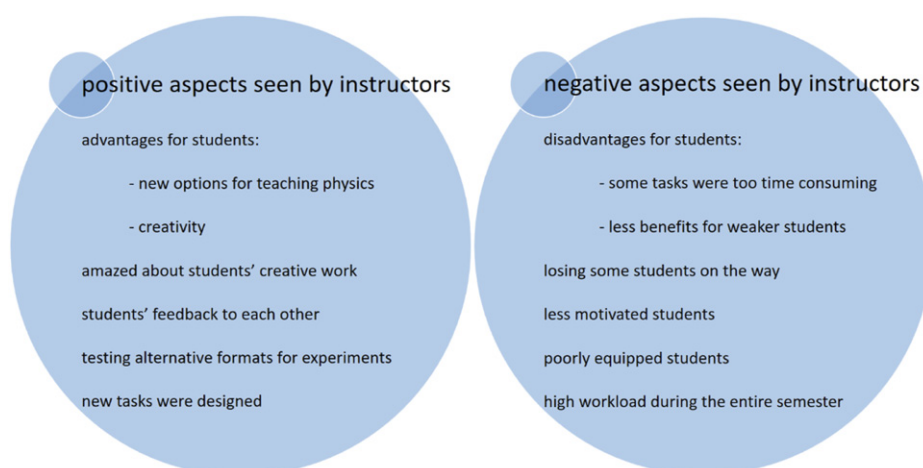


Figure 3. Positive and negative aspects reported by the surveyed instructors who teach the adapted lab courses at the Universities A and C ($N = 8$).

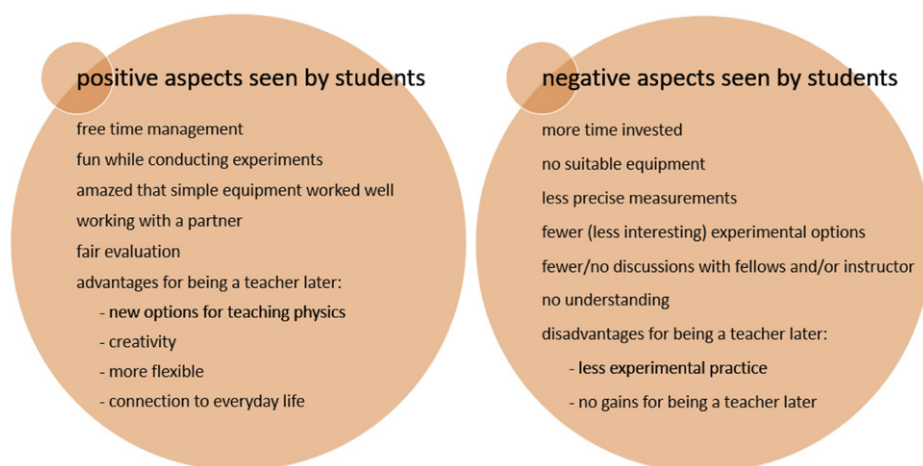


Figure 4. Positive and negative aspects reported by the interviewed students participating in the adapted lab courses at the Universities A, B, and C ($N = 10$).

fluent in both languages. With the help of the software for qualitative data analysis MAXQDA, students' answers regarding their experiences were structured and summarized by forming categories. Based on the interview questions, deductive main categories were first generated and then refined by creating inductive categories (following several iterations of qualitative content analysis, Kuckartz [20]). The system of categories was created in English, the common language of the researchers, and discussed within the group.

The instructors' survey was categorized in a similar way as the interviews and compared to the categories of the interviewed students.

Questionnaire item		University	University	University
		A	B	C
L1. I can perform most of the assigned experiments from home.	AGREE	29%	59%	63%
	DISAGREE	68%	33%	37%
L2. Conducting experiments at home has increased my creativity.	AGREE	39%	52%	80%
	DISAGREE	50%	36%	18%
L3. Since I conduct experiments from home, I am concerned that I will not be able to handle more complicated equipment one day in school.	AGREE	43%	45%	38%
	DISAGREE	50%	45%	60%
L4. Conducting home experiments convinced me that it is possible to conduct much more experiments in school than I thought before.	AGREE	47%	68%	83%
	DISAGREE	39%	16%	13%
L5. I am confident that I will be able to perform all the necessary experiments in school one day.	AGREE	71%	90%	80%
	DISAGREE	29%	7%	20%
L6. I like conducting experiments from home.	AGREE	32%	55%	50%
	DISAGREE	60%	36%	48%
L7. I spent more time per experiment from home than I would have spent performing the experiments at the university lab.	AGREE	67%	71%	85%
	DISAGREE	22%	20%	13%
L8. I like that I was not restricted by time when performing experiments from home.	AGREE	42%	63%	63%
	DISAGREE	48%	24%	30%
L9. I have a feeling that I did not understand the physics concepts behind the experiments because I performed experiments from home.	AGREE	32%	10%	13%
	DISAGREE	61%	71%	87%
L10. I have a feeling that I gained fewer experimental skills because I performed experiments from home.	AGREE	68%	52%	43%
	DISAGREE	22%	35%	57%

Figure 5. Percentages of students answers to some questionnaire items about laboratory courses for prospective physics teachers. In some cases when the percentages do not add up to a 100%, the difference is due to students' missing answers. The extent to which adaptations were regarded positively (green) or negatively (orange) by the relative majority differed between student groups.

The data pertaining to the students' questionnaire was coded by the software Unipark Quest-back and exported for standard frequency analysis. The four-point Likert scale was mostly used throughout the questionnaire and for the general analysis [9]. However, in this frequency analysis, it is convenient to present the data in a dichotomous form (agree/disagree) for clearer differentiations and comparisons between universities A, B, and C.

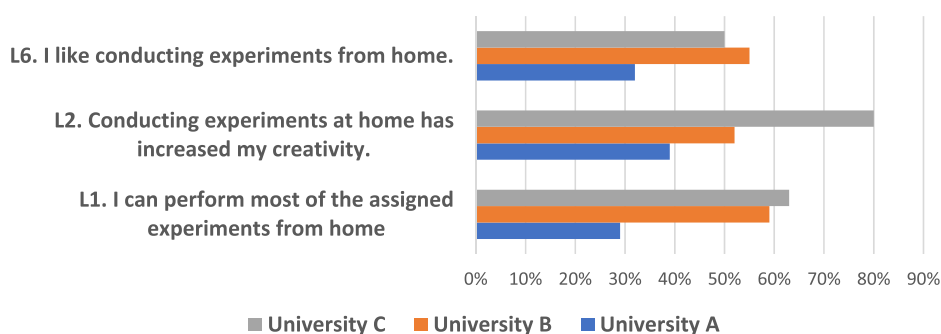


Figure 6. Percentages of students' agreements on items L1, L2 and L6.

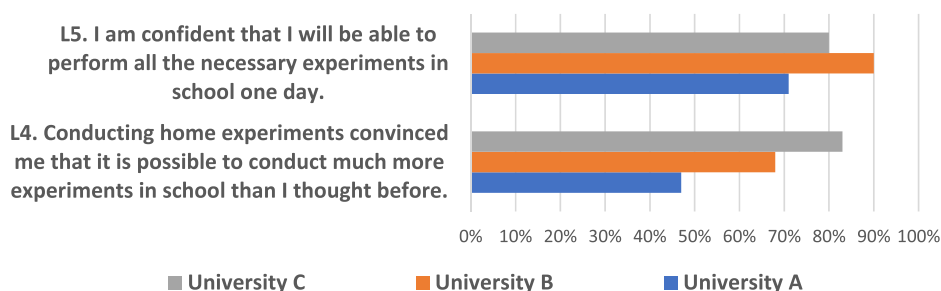


Figure 7. Percentages of students' agreements on items L4 and L5.

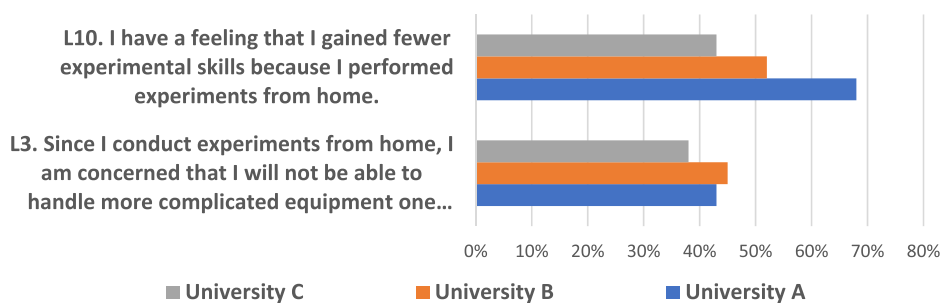


Figure 8. Percentages of students' agreements on items L3 and L10.

3.3. Research limitations

We are aware that there are limitations to this research since the percentages of students at University A who completed the questionnaire is lower than 50% of all students who participated in the laboratory course for prospective teachers. But we believe that this is enough to compare the courses and students' experiences during these adapted online courses and gain valuable information about similarities and differences among students' experiences, since the results of our qualitative and quantitative research are in line with each other.

Another limitation of this study may be due to the personal situation of some students and instructors. During the COVID-19 pandemic the general levels of stress and anxiety raised

among people with higher education [21]. This might have affected instructors and students during the semester and their readiness to participate in the study could have been affected because of the high levels of stress and personal insecurities.

4. Results

4.1. Instructors' survey

The surveyed instructors reported what changes were made and which consequences they had for the students' lab work. At Universities B and C no experiments were conducted and at University A significantly fewer experiments were conducted, so direct supervision of students was missing. Students at University A presented their experiments to their peers less often than usual; instead, written work and communication took priority during the lockdown.

Figure 3 summarizes the positive and negative aspects that the instructors reported about the adapted lab courses. Half of the surveyed instructors were satisfied at the end of the semester with how the online lab courses were conducted and even saw benefits for the students. The other half of the instructors were not satisfied because, for example, the practical lab work and students' presentations of the experiments in front of the groups were missing.

4.2. Students' interviews

The interviewed students reported on their experiences with the online lab courses and discussed positive as well as negative aspects. The summarizing categories are presented in figure 4.

Some students reported that they had very good access to necessary resources, but for others it was more difficult to obtain appropriate material and literature. Most of the interviewed students saw some advantages of conducting experiments at home. For instance, they saw new opportunities for teaching physics when everyday material is available and could be used for conducting school experiments. They appreciated home experiments because these types of experiments allowed them, as teachers, more flexibility, creativity, and a connection to everyday life. Furthermore, they became aware of the use of simulations in physics teaching. Other positive aspects that students highlighted were learning about new digital tools, having fun while conducting the experiments, and being amazed that it works well with such simple equipment. Students liked the collaboration with an online partner, the control over their time, and the fair grading (considering the circumstances they were in).

Nevertheless, some of the interviewed students thought that they learned less because the lab course was online. Thus, they conducted fewer experiments, handled less equipment, and used fewer experimental methods. Some students also found the home experiments difficult because they had no suitable equipment at home. They criticized videoconferences for being too short to talk about all topics in detail and saw disadvantages since the measurements with everyday material were not as precise compared to professional equipment. Students also reported missing in-person discussions with their peers and instructors and not getting the help they needed while performing the experiments from home.

4.3. Students' questionnaire

A sample of questions with percentages of students' agreement and disagreement about the laboratory for prospective teachers is presented in figure 5.

5. Discussion

The surveyed students were aware of different objectives of lab courses for prospective physics teachers (listed by Nivalainen *et al* [2], see section 1). They mostly stressed the development of practical and experimental skills and reported both positive and negative experiences in this respect. In addition, some of them addressed the objectives of fostering motivation, enhancing social and learning skills, and developing an understanding of science content and conceptual understanding in their answers. However, the objective of *developing an understanding of the nature of science and of scientific process* was not expressed by the instructors or students.

The analysis showed large differences between the three universities. Questionnaire answers of the students at University A often lean towards the other end of the Likert scale than answers from students at Universities B and C. Students at University A mostly disagreed with the statement *L1. I can perform most of the assigned experiments from home* (figure 5), and they did not like performing experiments from home (L6, figure 5). On the other hand, students at Universities B and C mostly stated that they can perform the assigned experiments and that they enjoyed conducting them. The benefits of performing home experiments were seen by both instructors and students as they felt it increased students' creativity and boosted their confidence in performing school experiments. This was especially the case when students were offered guidance and support in conducting experiments from home, either by working in pairs (University C) or/and through videoconferences with a lab instructor and peers (Universities B and C).

Even though students at University B and C were all required to do home experiments, unlike the students at University A, the lab course at University C stands out because this course required students to design the experiments on their own, reason about them, gather equipment, and perform the designed experiment. Students at University B did not have to design experiments, but only had to perform them using the equipment listed in the experimental task and did not experience all benefits of experimentation. At University C, the open inquiry tasks in the lab courses for prospective physics teachers were used long before COVID-19 lockdown and thus continued in the online setting. This approach is fulfilling the objectives stated by Prabha [22] and Yusiran *et al* [23] that lab courses should be designed to allow scientific inquiry instead of standard 'cookbook' lab instructions. Similarly, Holmes and Wieman [24] state the same for all introductory lab courses, not just ones for prospective physics teachers. The surveyed instructors of the lab courses at Universities A and C also liked the experimental assignments that students can solve at home and indicated that they would like to continue using new digital tools, for example, smartphone apps for measurements, simulations, or virtual experiments.

In summary, the analyzed data shows four general aspects of the online lab course for prospective physics teachers that most influenced students: *creativity, boosting confidence, support and guidance, and time commitment*.

5.1. Creativity

Most students at universities B and C perceived an increase of their creativity after performing home experiments (L2, figure 6). Three out of four instructors at University C also noticed and especially highlighted this benefit of promoting creativity. In addition, the interviewed students appreciated home experiments because they gave them, as prospective teachers, more flexibility, and a connection to everyday life.

Unfortunately, this was not often expressed by students from University A, where half of the students disagreed with the statement *L2. Conducting experiments at home has increased*

my creativity. Again, this is not surprising as 60% of the surveyed students at University A stated that they do not like performing home experiments (L6, figure 6) and 68% of them could not perform most of the assigned experiments at home (L1, figure 6). This is probably a consequence of the adapted online course format, where they were not obliged to do home experiments and did not receive instructors' support performing them.

Hut *et al* [10] and Pols [11] also report on students' productivity and creativity during home experimentation. Students often experience labs as cookbook courses to enhance the understanding of lecture content, but laboratories for prospective teachers should never be designed that way. Holmes and Wieman [24] argue the same for introductory lab courses in general. In addition, creative solutions for home experiments help to fulfill most of the course objectives, mainly developing practical and experimental skills, fostering motivation, and developing an understanding of the scientific process [2].

5.2. Boosting confidence

Students answers to item L4. *Conducting home experiments convinced me that it is possible to conduct much more experiments in school than I thought before* might suggest that students feel confident about finding adequate school experiments even without laboratory equipment (figure 7). The majority of students at University C agreed with this statement (83%), while less than half of the students at University A (47%) agreed with it. Answers to another item L5. *I am confident that I will be able to perform all the necessary experiments in school one day*, show that more students from University B and C, that were required to perform experiments, agreed with the statement than from University A.

In addition, students at University C are least concerned about being able to handle more complicated equipment once they start working at school because they performed experiments at home (L3, figure 8), and they disagreed more with the statement L10. *I have a feeling that I gained fewer experimental skills because I performed experiments from home* than students at universities A and B.

In the interviews, some students at University A expressed that they did not see any advantages of the online lab course and home experiments for their future teaching, which was not stated by interviewees from University B or C. They expressed concerns about conducting fewer experiments, handling less equipment, and using fewer experimental methods.

This aspect of confidence among students is much more expressed among students from University C. University C students received more support while performing home experiments, worked with an online partner and had a chance to discuss their experimental designs with an instructor via videoconferences before performing the experiments. University B students also expressed confidence about their future profession after performing home experiments, but not as much as students at University C. This might be due to the fact that they worked alone and not with a partner and discussed their experimental designs with a course instructor after experimentation and not before, as it was the case at University C. Students from University A showed the least confidence in performing school experiments, but they were not required to perform them and their experimental designs were not deeply discussed with instructors during videocalls.

5.3. Support and guidance

The most positive impact of the adapted lab courses in terms of the aforementioned aspects (*creativity* and *boosting confidence*) was seen in students at University C. As mentioned earlier, they received the most support and guidance when performing home experiments: they worked in pairs and had a weekly videocall with their instructor after designing the home experiments

but before performing them. Students at University B did not work in pairs and the weekly videoconferences with the instructor took place after they had performed the experiments. However, this seems to be less motivational for students than discussing the experiments during the creation process. In the interviews, students expressed missing in-person discussions in the lab and getting instructors' help when they encounter a problem. Due to guided discussions about the experiments and designs, it is possible that University C students feel much more confident when it comes to understanding the physics behind these experiments (L9. I have a feeling I did not understand physics behind the experiments because I performed experiments from home) and students at University A substantially less, 87% and 61%, respectively.

Thus, University B students showed less confidence in performing home experiments and indicated less increase in their creativity than University C students. Nevertheless, they expressed more benefits than University A students who were not guided and supported during the process of home experimentation and saw more disadvantages of home experiments than students at University B and C. In general, they lacked this guidance and support, which this research found to be of great importance. Some instructors also stated that support was missing, especially for weaker students.

In addition, conducting and discussing experiments in a group seems to be a prerequisite for fulfilling some of the objectives of the lab course for prospective physics teachers indicated by Nivalainen *et al* [2], namely, enhancing social and learning skills and fostering motivation.

5.4. Time commitment

Most of the students reported investing more time performing home experiments than they would have in a standard laboratory course at the university (figure 5, item L7). During the interviews, all students at University B also expressed their dissatisfaction with investing more time in experiments. Interestingly, the results of the questionnaire on item L8. *I like that I was not restricted by time when performing experiments from home* show that students at University B and C rather liked it: to have as much time as needed to perform experiments at their own pace. The interviewed students from University B and C also reported that they liked to manage their own time when performing home experiments.

The instructors also commented on the time commitment as a negative feature of online labs, similar to findings of Hut *et al* [10]. Adapting the experimental tasks to the online format required more time and increased the workload for them and the students.

6. Conclusion and implication for future teaching

For students attending the online lab courses for prospective physics teachers at Universities of Dresden, Vienna, and Zagreb, four aspects of the course seem to have the greatest influence on students. These aspects include performing home experiments and, while doing so, developing their *creativity* and *boosting their confidence* in conducting more school experiments than previously thought in their future teaching. These positive attributes were most emphasized by students that were given an open-inquiry task and had the freedom to design, reason, discuss, and perform experiments while working with an online partner and receiving the *support and guidance* of the course instructor. Although the home experiments required additional *time commitment* than a standard lab course at the university would, most students still liked being able to manage their own time without any constraints.

In the instructors' experience, students' *creativity* and *boosted confidence* were also seen as positive aspects of the online lab course. They even recommended conducting experiments with smartphones or tablets and using simulations and virtual experiments as part of a regular

course once the pandemic is over. Instructors expressed that in future lab courses, online consultations could be offered before the labs to discuss students' plans regarding the experiments. In addition to the positive effects, instructors experienced a higher workload and had to invest much more time in organizing the online lab course.

These accounts of students' and instructors' experiences with the online lab courses for prospective physics teachers answer our research question, from which guidelines for future lab courses for prospective physics teachers and similar courses can be formulated. We also believe that the following recommendations can be adapted for poorly equipped physics classrooms, allowing for more experimental practice in such schools.

Our recommendations for organizing online lab courses for prospective physics teachers are:

- (a) Give open-inquiry tasks that require simple home equipment for experimentation.
- (b) Pair students with an online partner (or a small group).
- (c) Give students time (e.g., a week) to research, design, and reason about the experiment.
- (d) Organize small group videocalls before students perform the experiments to discuss their experimental designs and potential problems, and to offer support and guidance with the tasks.
- (e) Give students time to perform the experiments (e.g., a couple of days) and ask reports with proof (pictures or videos) of the tasks.

One example of a successful open-inquiry task is asking students to design an experimental learning environment for exploring the Hooke's law. For this experiment a student might use the standard laboratory equipment, but as an alternative a spring can easily be replaced by a kitchen rubber band and weights can be replaced with a bag of coins. Once they explored that, they can use it in other experiments, e.g. for checking the law of conservation of energy when a bag of coins suspended on a rubber band oscillates between two positions.

From this point of view, the instructors and students appreciate the home-schooling experience because the findings and recommendations paved the way for easier reorganization and redesign of lab courses for the instructors for following lockdowns, and easier adjustment and organization of online courses for students. In addition, home experimentation as recommended could also be a beneficial component of regular lab courses for prospective physics teachers. Nevertheless, further research on the benefits of home experimentation is needed before integrating it into the regular lab courses.

Ethical statement

This study was carried out in accordance with the principles outlined in the Statutes for Ensuring Good Scientific Practice of University of Dresden [16], in the Mission Statement [17] and Statutes of the University of Vienna [18], and in the Ethical Codex of University of Zagreb [19]. In addition, all participants were volunteers and were informed about the research process and requirements, both verbally and in writing, and an informed consent was obtained from them.

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References

- [1] Etkina E 2010 *Phys. Rev. ST Phys. Educ. Res.* **6** 020110
- [2] Nivalainen V, Asikainen M A and Hirvonen P E 2013 *Phys. Rev. Phys. Educ. Res.* **9** 010102
- [3] Faulconer E K, Griffith J, Wood B, Acharyya S and Roberts D 2018 *J. Sci. Educ. Technol.* **27** 404–11
- [4] Kortemeyer G 2016 *J. Sci. Educ. Technol.* **25** 697–703
- [5] Vroeginday B J 2005 *EdD Thesis* Fielding Graduate University
- [6] Lindsey N S and Rice M L 2015 *J. Interactive Online Learn.* **13** 3 <https://www.ncolr.org/jiol/issues/pdf/13.3.3.pdf>
- [7] Scagnoli N I 2005 *Int. J. Instruct. Technol. Distance Learn.* **2** 10
- [8] Carrillo C and Flores M A 2020 *Eur. J. Teach. Educ.* **43** 466–87
- [9] Klein P et al 2021 *Phys. Rev. Phys. Educ. Res.* **17** 010117
- [10] Hut R W, Pols C F J and Verschuur D J 2020 *Phys. Educ.* **55** 065022
- [11] Pols F 2020 *Electron. J. Res. Sci. Math. Educ.* **24** 2
- [12] Bradbury F R and Pols F 2020 *Electron. J. Res. Sci. Math. Educ.* **24** 3
- [13] Fox M F J, Hoehn J R, Werth A and Lewandowski H J 2021 *Phys. Rev. Phys. Educ. Res.* **17** 010148
- [14] Peterson P L, Baker E and McGaw B 2010 *International Encyclopedia of Education* (Amsterdam: Elsevier)
- [15] Lowing K and Hartas D 2010 *Educational Research and Inquiry, Qualitative and Quantitative Approaches*, Continuum Pap/Psc edn (London: Continuum)
- [16] University of Dresden Statutes for Ensuring Good Scientific Practice 2021 https://tu-dresden.de/tu-dresden/qualitaetsmanagement/gute-wissenschaftliche-praxis-an-der-tu-dresden?set_language=en
- [17] Ethics Committee of the University of Vienna Mission statement 2021 <https://ethikkommission.univie.ac.at/en/mission-statement/>
- [18] University of Vienna Statutes of the University of Vienna 2021 <https://mtbl.univie.ac.at>
- [19] University of Zagreb Ethical codex 2007 https://www.hrstud.unizg.hr/images/50014335/Eticki_kodeks-1.pdf
- [20] Kuckartz U 2016 *Qualitative inhaltsanalyse Methoden, Praxis* (Computerunterstützung Weinheim und Basel: Beltz Juventa)
- [21] Salari N, Hosseinian-Far A, Jalali R, Vaisi-Raygani A, Rasoulpoor S, Mohammadi M, Rasoulpoor S and Khaledi-Paveh B 2020 *Global Health* **16** 57
- [22] Prabha S 2016 *Eur. Sci. J.* **12** 34
- [23] Yusiran, Siswanto, Hartono, Subali B, Ellianawati, Gumilar S and Sartika D 2019 *J. Phys.: Conf. Ser.* **1280** 052047
- [24] Holmes N G and Wieman C E 2018 *Phys. Today* **71** 38