Studying physics during the COVID-19 pandemic: Student perceptions on synchronous and asynchronous course formats and implications for the future

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To investigate how physics students perceived the sudden shift to online learning at the beginning of COVID-19 pandemic, 18 semistructured interviews were conducted with university students in Austria, Croatia, and Germany. Based on the interviews, a questionnaire was developed and data from $N = 578$ physics students from five universities in Germany, Austria, and Croatia were gathered. In this paper, we report how students perceived synchronous and asynchronous physics lessons, how their perception correlates with their self-organization skills, which activities and teaching methods were perceived as helpful, and what are the implications for future physics courses. The most common advantages of synchronous course elements reported by students were the possibility to immediately ask questions, the feeling of community and interaction with other students, and the defined daily structure, whereas the most common advantages of asynchronous course elements reported were flexible time management and the possibility to watch videos at their own pace. The data indicate a correlation between preference for synchronous courses and their general self-organization, so instructors should be aware of this connection when planning future courses. Face-to-face lectures at university were perceived as the most helpful course element, followed by the recorded lectures from the instructor and the group work on the assignments, projects, and problems with other students. Furthermore, our results suggest that most students would in the future like to preserve the upload of learning materials and recorded video of the lectures in addition to classroom lectures. Overall, the results of this study suggest that both synchronous and asynchronous course elements should be combined in future online and in-person physics courses.

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I. INTRODUCTION

In March 2020, the COVID-19 pandemic caused a sudden shift to online learning (e-learning) at schools and universities worldwide. Although e-learning existed before at some universities, most schools and universities were not prepared for such a change, and instructors and students needed to adapt quickly to the new situation. That included choosing an online platform for e-learning, deciding between synchronous and asynchronous online teaching formats, potentially selecting a video-conference provider for synchronous lessons, transforming the lesson and grading plans to make them compatible with e-learning, adapting tutorials and labs for distance learning, etc. Neither students nor the instructors freely decided to participate in or to teach an online course and the situation was different from the ones in which the universities offer the online courses as standard components of their curricula. One of the first decisions to be made was the one about the format of online courses. Several universities gave the early recommendation to offer as many courses as possible asynchronously in order to provide the same opportunities to all students, to facilitate the course

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participation for as many students as possible, and in order to account for a potential lack of technical equipment and different personal situations of students. A similar recommendation could be found on the PhysPort platform under the topic concerning the sudden move of the face-to-face courses to online courses: *"Recognize that not all your students will be able to attend synchronous online classes due to internet access, connectivity, scheduling, health, and family situations. Some platforms allow participants to call in via phone, which allow them to hear and participate in audio conversations, but not see slides, screenshare, or video. Find ways for students who can't connect in real time to still participate (e.g., by making recordings available after class), or consider not running synchronous classes at all: asynchronous learning can be much more equitable for students with different levels of access, health and privilege. These are also good things to keep in mind when you are teaching in-person classes"*. [1]

Even before the COVID-19 pandemic, there were some universities that offered online courses and there is a body of research about e-learning in general [2–18]. There are a variety of ways how to structure the overview of previous research on online learning, and we have decided to focus on those aspects of research that are most relevant for the analysis of synchronous and asynchronous teaching formats. These aspects include research about the video lectures and instructors' as well as students' perceptions about them [4,5,15–23], students' engagement, interaction, and achievement in e-learning courses [2,3,7,11], students' motivation [13], and more specifically synchronous and asynchronous online courses [24–26].

The recording of live lectures, or lecture capture, has become a very common technology in higher education even before the COVID-19 pandemic [5,19], but became one of the most commonly used lecture delivery methods during school closures [19]. Despite the widespread use of captured lectures, its impact on student learning and attainment is still not clear [19]. There are a wide variety of designs of captured lectures starting from voice over slides or screen, fixed or mobile frames outside or over recordings in which the lecturer is present in the video frame next to the slides to direct recording in a traditional lecture context [4]. Recorded lectures are also used for a wide variety of reasons, ranging from revision of the lecture content for the exams, to review of complex material or to pick up on sections one missed in the live lecture, to recover the lectures one missed due to absence from the live lectures, to gain more control over learning, and to assist students having difficulties with the lecturer's spoken language. In some cases, recorded lectures or pre-recorded short video clips may be used to replace the prereading lecture assignment in flipped-classroom settings [17]. Students believe that captured lectures increase their course performance [27], but this is not clearly supported by the research, with some studies supporting that claim [21,28], and others showing little or no influence of using captured lectures on course grades [22,23]. The use of captured lectures and the viewing times also vary across disciplines, with science, technology, engineering, and math students having significantly longer viewing times than students in other subjects [18]. A study by Dommett *et al.* with 522 students and 95 lecturers showed that they perceived the captured lectures differently, with students being more positive about captured lectures but perceiving less need for participation, whereas the instructors have less favorable views of it and also felt that students must be more active in their participation [5]. Morris [18] came to similar findings, together with reporting a smaller attendance rate of lectures that were recorded compared to those that were not recorded. Wood *et al.* [20] explored the use of captured lectures in introductory physics and mathematics courses at the University of Edinburgh in flipped and nonflipped classroom settings. Students in that study preferred to attend live lectures because they gave them the opportunity to ask questions, because of social contact and social pressure to concentrate, and because of getting out of their own apartment. One common reason for their preference was that active-learning flipped classes gave them experiences that would not be gained from watching the lecture online, such as discussing with other students, whereas for the nonflipped classes in which a large amount of information was communicated, students found that lecture captures were helpful and they used them more frequently [20].

A second important research strand includes the research about the factors that predict students' achievement and comparison of students' achievements in different types of courses. Bernard *et al.* developed a questionnaire for predicting online learning achievement [3]. They found that two factors are positive predictors of learning achievement measured through the course grade and these are "self-direction" and "beliefs," where self-direction stands for good self-organization skills and beliefs stands for "general beliefs about online learning" [3].

However, most of the research mentioned above does not evaluate specifically physics courses and it focuses on courses that were planned as online courses from the beginning which differs from the situation during the COVID-19 pandemic in which both instructors and students were forced into e-learning.

In physics, some resources for online teaching and learning were developed in the last years [29–36]. One of the models includes massive open online courses (MOOC). The research of Colvin *et al.* showed that the learning gain in open online introductory physics courses was similar to learning gains in traditional face-to-face physics courses, but lower than in interactive face-to-face physics courses [29]. However, most of the resources for online teaching were not meant to replace the face-to-face physics courses, but to supplement them. These include online homework [30–34], remote labs [36], simulations [35], and online quizzes. Simulations and virtual labs have shown positive effects on students' learning [35,37].

In the meantime, there was more research published about the e-learning in the times of the COVID-19 pandemic [24,38–41]. The study from Coastal Carolina University, USA, explored the transition to online learning for introductory physics students in synchronous and asynchronous settings [24]. The results have shown that students who attended optional synchronous sessions had a smaller drop in students' exam grades and achieved a better normalized gain on their pre-post assessment. Guo concluded that the transition was smoother for students who attended synchronous sessions [24].

The work from the University of the West Indies, Republic of Trinidad and Tobago, reports five lessons learned from teaching the introductory digital electronics course during university closure in Spring 2020. These include the importance of presenting students with a variety of learning resources to facilitate their study of the subject, the importance of visual tutors with the ability of interaction, and feedback for student learning of the course material, the importance of consultations with the course lecturer, the importance of a concise and reliable workbook for the course delivered by the lecturer, the benefits of mock exams that promote student learning of the topics being examined as well as to get students acclimatized with the attempting of exams on the online platform [38].

Sahinidis and Tsaknis explored the relationship between personality factors (openness, conscientiousness, extraversion, agreeableness, neuroticism) and student satisfaction with synchronous online learning on 555 students at a Greek public university in Athens [42,43]. The findings indicate that openness and conscientiousness have a strong positive influence on student satisfaction with synchronous online academic learning, neuroticism has a negative influence, and extraversion and agreeableness did not relate to the dependent variable.

Doucette *et al.* conducted the study on student reflections on different aspects of online learning [41]. Most of the students participating in the study were in introductory physics courses ($N = 1109$). According to those students the biggest advantage of live online lectures was that they could rewatch the lectures and catch up on the concepts they missed, while the biggest concerns of students were motivation, focus, and mental health [41]. The authors recommend for online courses as well as for flipped classes many low-stakes grade incentives interspersed throughout the course and more frequent, low-stakes (formative) assessment, and less weight on a final exam in order to prevent skipping office hours and falling behind and also reducing student anxiety.

In our first paper, we investigated how students perceived physics problem-solving sessions (so-called recitations), physics laboratory courses, and the relationship between perceived learning effectiveness during the COVID-19 summer term 2020 and the various behavioral aspects that are important in e-learning [44]. In addition we investigated students' and instructors' considerations about the experiences with laboratory course for future physics teachers [45].

The aim of this paper is to provide an overview of the student attitudes towards different formats of e-learning and, in particular, their perception of synchronous and asynchronous physics courses.

The main research questions that this paper aims to answer are

Q1: Which course formats during unexpected e-learning situations did students prefer and why?

Q2: Which course elements did students find helpful for their learning?

Q3: What are the implications for the future—what can we learn from this situation and which online formats do students want to preserve even after the COVID-19 pandemic?

II. THEORETICAL BACKGROUND

"Synchronous e-learning" has been defined as learning that happens in real time during the lesson which is supported by media such as chat and/or video conferences that, in turn, has a potential to support students in the development of learning communities, and is also perceived by learners and teachers as more social. In contrast, "asynchronous e-learning" is characterized by participants as not being online at the same time, is flexible and learners can log on to a learning environment or send messages, emails, or contributions to discussion boards, colleagues, and instructors at any time [25]. Hrastinski defines the benefits and limitations of synchronous and asynchronous learning based on the three types of communication that are important for building and sustaining e-learning communities: content-related communication, planning of tasks, and social support. The classification of sentences from seminar discussions in knowledge management classes showed that in the asynchronous discussions more than 90% of the sentences were classified as content related, which could lead to the conclusion that students might feel isolated and not as much a part of learning communities, which is essential for communication and learning [25]. In synchronous discussions, around 60% of the sentences were classified as content related, about 30% as planning of tasks, and a little bit more than 10% as social support and things other than class work. Based on these results, Hrastinski developed a model for cognitive and personal participation in e-learning settings, which is presented in Fig. 1. In conclusion, he suggests using synchronous e-learning for discussing less complex issues, getting acquainted and planning tasks, and asynchronous e-learning for reflecting on complex issues and when synchronous

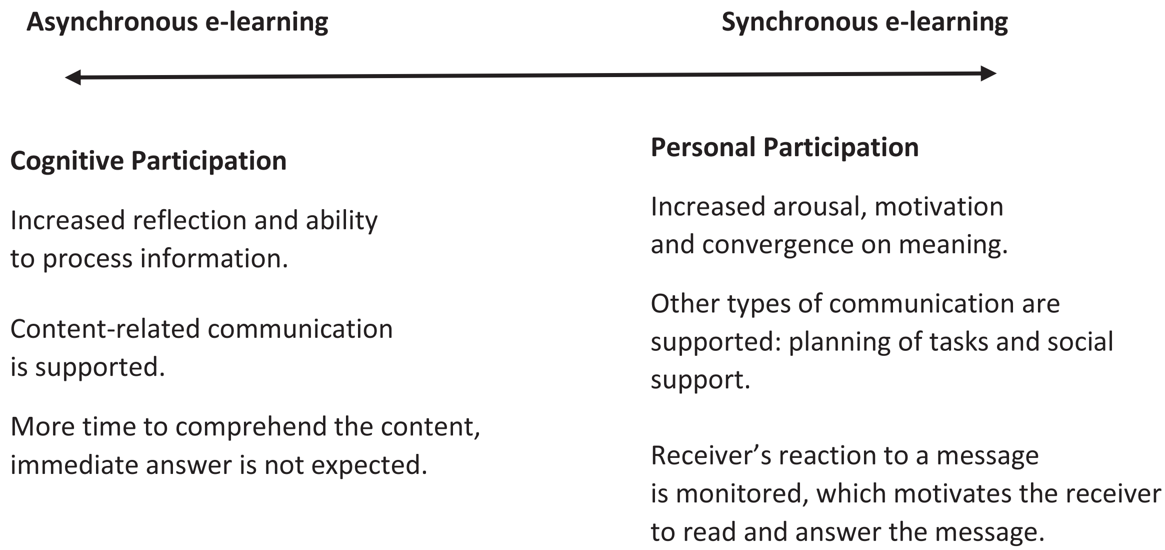

FIG. 1. Cognitive and personal dimensions of e-learning, modified from Ref. [25].

meetings cannot be scheduled because of work, family, and other commitments [25].

While Hrastinski describes the communication between students, Anderson [46] has developed an equivalency theorem for communication in distance learning saying: "*Deep and meaningful formal learning is supported as long as one of the three forms of interaction (student–teacher; student-student; student-content) is at a high level. The other two may be offered at minimal levels, or even eliminated, without degrading the educational experience. High levels of more than one of these three modes will likely provide a more satisfying educational experience, though these experiences may not be as cost or time effective as less interactive learning sequences.*" Bernard *et al.* have published a meta-analysis of these three types of interaction in distance education with the goal to investigate which combination of interactions has the strongest effect on the learning achievement [2]. They found out that the best learning outcomes were achieved with the combinations that included student-content interaction: student-student interaction in combination with student-content interaction, and student-instructor interaction in combination with student-content interaction.

III. METHOD

A. Interviews

In the first project stage, the interview guidelines that included five aspects of online teaching during the COVID-19 pandemic were developed. The interview guidelines included questions about general aspects of e-learning, questions about attitudes to synchronous and asynchronous teaching, a comparison of on-campus courses and online courses, questions about course requirements and expectations about learning achievement, and specific questions about the organization of lab courses. Semistructured interviews were conducted with 16 physics students aiming to become physics teachers and 2 engineering students from the University of Vienna, Austria, University of Zagreb, Croatia, TU Dresden, University of Göttingen, and University of Kaiserslautern, Germany. Interviews lasted for 33–94 min. This paper focuses on the part of interviews about the synchronous and asynchronous teaching formats as well as the implications for future courses. Table I shows the main interview questions about course formats and the expected interview outcomes. If the students' answers were incomplete, the interviewer asked additional questions to get more insights into their answers.

B. Questionnaire development

Based on the previous literature on e-learning [3], the results from conducted interviews, and our own experiences with the transition to e-learning, the first set of research questions and topics for the questionnaire were defined. The whole questionnaire about students' perception of e-learning included 246 technical data fields which were divided into 14 subtopics. Ten of these subtopics were general and addressed to all physics students. These included general information about tools used for e-learning, demographic data, self-organization skills (general and during COVID-19 semester), learning environment, attitudes to synchronous and asynchronous teaching, helpfulness of different course activities, attitudes toward online learning, communication, expected learning achievement in the physics courses, and implications for future courses. Four additional subtopics concerned different course formats like recitations, physics labs, labs for future physics teachers, and school practice.

TABLE I. Interview questions related to synchronous and asynchronous physics courses and expected interview outcomes.

	Interview question	Expected interview outcomes
1.	In this semester, the university has to make an unplanned switch to distance learning. How do you perceive this change? Please describe in general: How is online teaching implemented?	Personal perception of distance learning
2.	Please describe how you cope with online teaching in the current situation.	Personal situation of students; accessibility of technical equipment and internet connection, and a quiet learning environment
3.	Now let's take a closer look at the teaching formats. Please describe which forms and formats of online teaching take place this semester. In case that students had not described synchronous and asynchronous course formats, the interviewer asked more specific questions.	Students explain the synchronous and asynchronous physics courses or the combination of both.
4.	Which of these formats do you find more helpful in achieving your goals in a particular course? Please explain.	Helpfulness of different course formats
5.	Which course formats (synchronous or asynchronous) do you prefer? Would you rather prefer to use certain formats more or less frequently? Please explain.	Preferences for synchronous and asynchronous courses and the reasons.
6.	Do you take part in synchronous teaching? What motivates you to take part? Please explain.	Motivation for participation in synchronous course formats
7.	Do you take advantages of all forms of asynchronous teaching (for example: read the texts that are made available, watch the videos …)? What motivates you to do this? Please explain.	Motivation for participation in asynchronous course formats
8.	What advantages and disadvantages do you see in the different forms and formats of online teaching (synchronous, asynchronous)?	Advantages and disadvantages of different course formats
9.	Please describe what you miss during the current online teaching. What would you wish for?	Implications for the future online courses
10.	Which elements of the online courses would you like to keep even if the courses at the university are possible?	Implications for the future courses after the COVID-19 pandemic

In this paper, we focus on the attitudes towards synchronous and asynchronous teaching, the helpfulness of different course activities, and implications for future physics courses. Other scales are described and reported in another paper [44].

C. Data collection and sample

1. Different course formats at participating universities

All five participating universities are public European research universities offering predominantly in-classroom courses at university. At the beginning of the COVID-19 pandemic in Europe, the classes at two participating universities had already started (University of Zagreb and University of Vienna), while classes had not yet started at the other three universities. Nevertheless, the switch to e-learning was sudden and unexpected at all five universities. At the beginning of the transition to e-learning, it was recommended at some universities to offer asynchronous classes in order to enable more students to participate in courses and to take into account the lack of technical equipment and different personal situations of different students, but in most cases it was up to the instructors how they designed the courses. For this reason, a wide variety of different e-learning formats were offered, from completely asynchronous courses to mixed courses in which some parts of the courses were synchronous, and others were asynchronous to completely synchronous courses.

2. Interviews sample

Eighteen semistructured interviews were conducted in May 2020 with students from five universities. The sample included 9 male and 9 female students. All students participating in the interviews were volunteers and they were interviewed using the video conference tools Zoom [47] or BigBlueButton [48]. All students were conveniently sampled, which means that participants were chosen based on their convenient accessibility [49]. All interviews were recorded and transcribed. No course credits or other rewards were given for the interview participation. Students were distributed between the 2nd and 17th semester. Table II summarizes the information about interviewed students. Sixteen of interviewed students were

TABLE II. Information about the interview sample.

City	Number of interviewed students	Percentage of females (%)	Semester from the beginning of study	Duration of interviews (min)
Dresden	4	50.0	4th, 8th, 9th, and 10th	61–74
Göttingen	3	66.6	4th, 6th, and 17th	33–50
Kaiserslautern	1	0	7th	33
Vienna	4	25.0	4th, 5th, 6th, and 7th	53–94
Zagreb	6	66.6	2 × 2nd, 6th, 2 × 8th, and 10th	35–63
SUM	18	50.0		

physics students in the field of study to become physics teachers. Two students from the University of Zagreb were engineering students, they were in the second semester of their studies and were participating in an introductory physics course. All physics students were in the 4th semester or higher, as we also wanted to evaluate the physics education courses for future physics teachers, and these take place starting in the 4th semester.

3. Questionnaire sample

The questionnaire was administered to physics students at the end of summer term 2020 in June and July using the Questback tool for questionnaires [50]. The participation in the questionnaire was voluntary, and it was distributed using central university email lists and through faculty. Overall, the participation link was sent to 2700 students, and 873 students clicked on the link (32.3%). We received completed questionnaires from 578 physics students (352 male, 226 female), yielding participation rates of 21.4% (total participation rate, TPR) and 66.2% (adjusted participation rate, APR), as measured by the completed surveys to invited students and completed surveys to interested students, respectively. The TPR ranged from 11% (Dresden) to 57% (Zagreb), and APR ranged from 53% (Kaiserslautern) to 72% (Göttingen). The average time for answering the questionnaire was 24 min 37 sec. Table III summarizes the information about the participating students and universities [44].

D. Data analysis

1. Interviews

The transcribed interviews were analyzed in their original language (Croatian or German). The analysis was done using the framework of qualitative content analysis by Kuckartz [51]. In the first step, deductive categories were built, and then they were grouped as well as organized thematically and refined by creating inductive categories. The analysis was conducted using software for qualitative data analysis MAXQDA [52]. The results were compared and discussed with other team members.

2. Questionnaire

Table IV shows the characteristics of the questionnaire scales. For each item, a 4-point Likert-type scale was used. Thus, the means range between 1 and 4 points, where high values correspond to high abilities or preferences. The response options included options “strongly disagree, disagree, agree, and strongly agree.” The option “neutral” was not included in order to prevent respondents to misuse the midpoint [53]. The statements included in the scales presented in the Table IV included the context familiar to the students, so we think that was appropriate to avoid the option “neutral.” The scales and the psychometric validation of the instrument structure using a confirmatory factor analysis are reported in our first paper [44], and one more scale about asynchronous courses has been included in this paper. All scales were confirmed to be one dimensional. The internal consistency of scales was measured by the

TABLE III. Information about the questionnaire sample. The number in brackets are percentages of the students belonging to different groups out of all students. All students participating in the study are divided in groups between studying less than 1 year to studying more than 6 years.

			Duration of studying physics				
	Total sample	Male (%)	<1 yr	1–2.5 yr	3–4.5 yr	5–6 yr	>6 yr
Dresden	114	73 (64.0)	39 (34.2)	30 (26.3)	30 (26.3)	12 (10.5)	1 (0.9)
Göttingen	232	144 (62.1)	83 (35.8)	62 (26.7)	62 (26.7)	19 (8.2)	6 (2.6)
Kaiserslautern	9	5 (55.6)	4 (44.4)	2 (22.2)	…	2 (22.2)	1 (11.1)
Vienna	138	85 (61.6)	30 (21.7)	65 (47.1)	24 (17.4)	11 (8.0)	7 (5.1)
Zagreb	85	45 (52.9)	25 (29.4)	27 (31.8)	23 (27.1)	6 (7.1)	4 (4.7)
SUM	578	352 (60.9)	181 (31.3)	186 (32.2)	139 (24.2)	50 (8.7)	19 (3.3)

TABLE IV. Description and psychometric characteristics of the scales that were used for all students. The mean scores obtained from the rating scales were linearly transformed to a percentage scale where 0 means lowest and 100 means highest expression. The percentages are provided in parentheses.

Scale	Number of items	Sample item	Reliability (Cronbach's alpha)	Mean score ± standard deviation (Percentages)
Synchronous courses	6	Synchronous activities help me to understand the learning content more than asynchronous activities.	0.83	2.86 ± 0.63 (62.0 ± 21.0)
Self-organization abilities in general	5	In my studies, I am self-disciplined, and I find it easy to set aside reading and homework time.	0.76	2.97 ± 0.57 (65.6 ± 25.5)
Self-organization abilities during COVID 19-semester	6	Not being at university hinders me from studying[a].	0.77	2.41 ± 0.67 (47.1 ± 22.4)
Environment	2	I have a quiet space where I can participate in video conferences unhindered.	0.90	3.11 ± 0.76 (70.4 ± 19.1)
Face to face preferences (vs online)	6	Classroom instruction helps me to understand the physics concepts better than in online courses.	0.75	2.84 ± 0.80 (61.5 ± 26.5)
Communication	8	It is easy for me to establish contacts with other students during the COVID-19 pandemic.	0.88	2.19 ± 0.57 (39.5 ± 18.9)

[a]Negative statements were reversed for the analysis.

reliability coefficient Cronbach's α that indicates how well the items "fit together." Cronbach's α was greater than 0.7 for all scales, indicating that the scales are reliable for group measurements.

For determining the relationships between the preference for synchronous courses and other scales, Pearson's correlation coefficient was used. The correlation analysis was performed at the level of the variables, that is, the mean values aggregated over all items of one scale. Pearson's correlation coefficient measures the linear correlation between two variables and ranges from -1 to 1. A value of $+1$ means a completely positive linear correlation, 0 corresponds to no linear correlation, and -1 indicates a completely negative linear correlation. Furthermore, in order to evaluate the reasons for a positive (or negative) attitude towards different teaching methods or materials (recorded lectures, uploaded lecture notes, and synchronous lectures), the correlation between the attitude scores and the ratings of different characteristics of the respective methods (i.e., pausing videos, learning at own pace, etc.) was investigated.

To assess which activities students found helpful, a list of typical activities was compiled that included, for example, recorded lecture videos, group work with other students, and synchronous lectures. Finally, a post-hoc quartile split was applied to compare the perceived usefulness of different teaching formats between student groups with strong preferences for synchronous vs asynchronous teaching formats. For this quartile split, all students in the top or bottom quartile concerning their scale values for group comparison were included. Unpaired t tests were used to compare both student groups. Cohen's d was calculated by dividing the group mean difference by the pooled standard deviation. A threshold of $p = 0.05$ was used for determining the level of effect significance within all conducted t tests. It is usually considered that Cohen's d 0.2 indicates a small effect size, 0.5 a medium effect size, and 0.8 a large effect size.

E. Limitations of the study and ethical considerations

Physics education research relies on human samples, and this reliance brings many ethical questions, one of which is the collection of data during a pandemic. The research project was conducted in Europe, and at the time when the interviews were conducted and the questionnaire was administered most of the students at participating institutions were not affected by the health problems due to COVID-19, but they were facing isolation and high levels of stress due to the new situation. In deciding whether to conduct the study, we considered the burdens and the benefits of the study in terms of future courses. The students surveyed were given an informed consent letter in advance, in which they were provided with all relevant information about the study and their potential role in it, about the protection of their information and privacy, and they were informed that they could stop the interview at any time without consequences. The same information was also given to students before completing the questionnaire. The participation in the study was voluntary, and there was no awards or negative consequences for the students. This is also the limitation of the study, and we assume that the students who wanted to express their feelings during the e-learning situation participated in the study and that we probably did not reach the students who really struggled.

In addition, participation in the study required a computer or a smartphone and an internet connection, which could have been an obstacle for some of the students. The participation rate of 20% in the questionnaire could be due to students being overwhelmed with different questionnaires during the online semester, demands on students' time, or students not seeing personal relevance in the survey. Regarding the low participation rate, we cannot claim that results of the questionnaire are representative of all physics students.

IV. RESULTS

A. Online tools and technical and personal situation

During the interviews, one of the first questions asked was how students were coping with the online courses during the pandemic and whether they had all the necessary requirements to take part in the online lessons. All students interviewed reported that they have all technical requirements (computer and internet connection), although three students did not have a stable connection and 2 out of 18 students interviewed reported that they lacked a quiet working space, which made it complicated for them to actively participate in synchronous classes. One of the students described the situation as follows:

> *"I live with my partner, and in the first few weeks when we switched to e-learning, for example, he always had a four-hour lecture during our synchronous lab discussions, and that's why I just didn't want to talk so much that I somehow didn't disturb him. And then I tried to write in the chat during our online class to show that I was there. So, I think it's a problem when, uh, you don't have that much space [in your apartment]." [UV04]*

The other student reported that he has all the necessary prerequisites for online learning and experiences it convenient for his personal situation, but has problems with motivation and self-discipline:

> *"So basically, as far as I use it, I'm fine with it [prerequisites]. I think it is a pity because it is not the same as when I was at university. So, for me personally, it has just lost quality. And my biggest point is just the motivation because for me it's a difference if I get up at eight and I'm in the university … And then I think to myself: Well, I'll sleep until nine or half past nine. So, I think I'm just more productive in normal university life. Above all, I find it very difficult to study at home … It just takes a lot of self-discipline and I'm so self-reflective that I often do not have that … I find for my personal life …. I find it basically very convenient because you're just more flexible. So, I can really say, okay, I'll do this [work for university] later." [UV02]*

In the questionnaire, students were also asked about their technical and personal situation during the e-learning. These aspects are important when making decisions about synchronous and asynchronous course elements because insufficient technical equipment and internet connection are possible reasons to decide for asynchronous course elements. Almost all participating students reported having permanent access to a PC (95%) and most of the students reported access to a fast and stable internet connection (81%).

B. Synchronous and asynchronous course formats

1. Interview results

All interviewed students have experienced both synchronous and asynchronous course formats. The synchronous course activities included physics lectures, question and answer sessions, recitations where one student solves the problem, discussion sessions before the labs and discussions in the seminars, while asynchronous activities included uploaded lecture videos, uploaded power point presentations with and without audio, uploaded scripts and assignments that needed to be solved and uploaded in the learning platform.

When asked which format they preferred, eight students gave preference to synchronous formats, two students preferred completely asynchronous formats, and eight students thought that the mixture of both was the best solution. Five students said explicitly that they would like to have more synchronous formats, and three students commented that the quality and how the course is conducted is essential for the format preference. The following student's answer illustrates this: *"If a lecture is just held by the lecturer and no questions are actually asked, I don't really find this [type of] live lecture necessary. Then it is better if I can watch it at another time when it is just uploaded and always available." [TUK01]*

When asked about the attendance of the synchronous lectures, eleven of the interviewed students said that they attend them regularly. The main reasons included the requirement from the lecturer, the regular daily structure, not to skip anything, because it is easier to learn that way, to ask questions and to hear questions from others, and because they appreciate the effort instructors put into their classes. When looking at the results from the questionnaire, 47% of the students stated that they regularly participate (in 81%–100% of classes) in synchronous class formats, while 11% of them stated that they do not participate in synchronous class formats (in 0%–20% of classes).

Five of the students interviewed completed all asynchronous tasks and materials. The motivation for working through asynchronous materials was the interest and the desire not to waste the semester and to be prepared for the exams at the end.

Next, we asked students about the advantages and disadvantages of synchronous and asynchronous courses. The summary of categories, examples of student quotes, and their frequencies are given in Tables V and VI. These

TABLE V. Advantages and disadvantages of synchronous physics courses.

Advantages of synchronous physics courses	Examples of student quotes from the interviews	Number of students
Possibility to immediately ask questions	*"You can ask questions when something comes up. And you don't always have to write e-mails afterwards. So, you can address the problems right away, which is very helpful." [TUD03]*	9
Feeling of community and interaction with other students	*"And a big factor is simply this social component because you sit at home, you have little contact with your fellow students because you don't know every student, and when you just hear someone or see someone, it's simply … you have this feeling again: "okay, I'm not the only student in the world who might be struggling right now. This is certainly the big advantage that I see." [UV02]*	6
Defined daily structure	*"So, I think the synchronous formats are more helpful because they give the students and me a regular schedule. And so I can plan my week better, which I think makes life a little easier for all the people who maybe aren't so good at time management, I think." [UV02]*	5
Perception to understand more and to get the information that is important	*"It is useful that some things that we cannot understand on our own are repeated, the instructor emphasizes them, and then we know that we need to pay attention to them. Especially when the instructor explains the problems, then we know that this is essential for this unit, but not only now, but also for the next unit–in this way we know what things are important for us." [UZ02]*	3
Social pressure as a motivation factor	*"For me, the synchronous classes where we see each other are better. For example, this lab course once a week where I know that we will see each other via Zoom and that I need to complete my assignments—that is what motivates me." [UZ01]*	3
Similarity to "normal" courses	*"But in my opinion, one is more dynamic in synchronous courses, and everything is a bit more interactive, and it is more like natural learning." [UV03]*	3
Disadvantages of synchronous physics courses		**Number of students**
Technical circumstances make following classes and communication difficult	*"Video conferences are always like… it's just kind of exhausting. Fifty percent of the people don't have suitable microphones for it, which is understandable, and that's okay. No one can do anything about it. Then, simply because of the existing technical latency, people are constantly talking to each other. Or there is just a hard moderation, which then also somehow interrupts the discussion again. So, the technical limitations that are just inherently there make the whole thing a bit idle, from my point of view." [TUD02]*	4
Insufficient activation	*"In synchronous classes instructor does not have that strength to get us to participate so much. You turn off the microphone and it's over and no one can make you talk. So, there is often this uncomfortable silence." [UZ03]*	1
No permission to record	*"I think the big disadvantage of the synchronous is just, for data protection reasons, that the recording is not possible or only with difficulty." [TUD04]*	1
Videoconferences are dragged	*"That's just the time factor, especially now via the online communication channel here, many things drag on extremely long, where you might think you could do it a bit faster, etc. So that you sometimes just really, simply put, listen to fellow students asking about things where you just think: "That's obvious". So that can sometimes get a bit annoying over time. But … yes, you just have to accept it sometimes." [UV03]*	1

frequencies are the counts of students who mentioned a particular advantage and disadvantage during the interview and part of the qualitative analysis.

As can be seen from Table V, the students interviewed in total saw more advantages than disadvantages in synchronous physics courses. The main advantages include the possibility to immediately ask questions if something is not clear, which was mentioned by nine students, and the interaction with other students, which gives the feeling of community, which was mentioned by six students. Five students saw as one advantage that synchronous courses gave them the daily structure and help them organize their

TABLE VI. Advantages and disadvantages of asynchronous physics courses.

Advantages of asynchronous physics courses	Examples of student quotes from the interviews	Number of students
Flexible time management	*"But it's also the case that I find it quite convenient to organize things myself. Since I get up relatively early and have a lot of courses in the afternoon this semester, my attention threshold has already dropped. So, I find it better if I can do something for the university right at seven o'clock in the morning, when the lecturers might not even be awake yet." [UV04]*	7
Possibility to watch videos at the own pace (slower, faster, more times)	*"The huge advantage of recorded lecture videos is, of course, that I can watch them at any time, and I can check at any time: okay, what was said there, okay, I made a mistake here, well, I can review that again. That's a huge advantage, I really liked that last semester. Because it wasn't just PowerPoint presentations, you could also follow the words of the lecturer, who explained things on the side, and the audio-visual was very helpful." [TUD04]*	4
Possibility to concentrate better	*"And you can probably concentrate a bit better when watching the videos because there's no one sitting next to you to chat during the lectures." [TUD03]*	1
Disadvantages of asynchronous physics courses		**Number of students**
Missing fixed daily structure due to flexible time management	*"The problem is to get up in the morning and go to work, especially if the lectures are recorded, then you postpone, you postpone… you end up watching them at 10 in the evening." [UZ06]*	5
Missing possibility to immediately ask a question and get the answer	*"The only disadvantage I see with the asynchronous ones is that you can't ask any questions." [TUD04]*	4
Missing communication with other students	*"When you're sitting all alone in the middle of the night in front of a video that someone has recorded, I find that you lose even more contact, the connection." [TUG01]*	3
Missing support and structured learning materials	*"I need to do everything by myself. A lot of reading, researching, and putting together different documents that the instructors upload. They give us 4-5-6 documents for one lecture and say read this. And then it takes a lot of time to go through everything, condense it, and create a useful document that contains all these 6—and this takes a very long time." [UZ03]*	3
Missing interesting aspects of classes	*"But you don't look outside the box, and you don't get new inputs that are very interesting and that actually make up the highlights of units. And then it is really a certain minimum that has to be fulfilled. But no more and no less." [UV03]*	1

days and weeks better, which helps with time management. On the other hand, technical difficulties were mentioned as the biggest disadvantage of synchronous courses.

When talking about the asynchronous course formats, the students mentioned flexible time management as both the main advantage and disadvantage at the same time. Seven students saw flexible time management as an advantage and five students saw it as a disadvantage, and three students saw it as both an advantage and a disadvantage, as shown in the following quote: "*Again, I would say that everything has its advantages and disadvantages. You can distribute the work the way you want. But the thing that I was also talking about before, that you often postpone it. So you start with less important tasks or so, which would actually have a lower priority.*" [TUG03]. Four of the students interviewed also liked the idea of watching recorded videos at their own pace, which includes stopping the video and watching it several times, but also watching it faster using the fast forward function. At the same time, four students were missing the possibility to ask questions immediately if they did not understand something. Table VI gives an overview of all the advantages and disadvantages that students mentioned about asynchronous courses.

We have also asked students what they are missing in online courses, and they ranked the social component and interaction with other students first (9 students), followed by the direct contact with the instructors (5 students), motivation to complete the assignments (4 students), being at the university (3 students), experiments in labs (3 students), well-written materials (2 students), access to the library (2 students), fixed office hours (1 student), and feedback (1 student).

TABLE VII. Correlation analysis. Significant correlation coefficients are indicated by $^{*}(p < 0.05)$ and $^{**}(p < 0.01)$, respectively.

	1	2	3	4	5
(6) Preference for synchronous courses	0.139**	−0.076	0.072	−0.248**	−0.0437
(1) Self-organization in general	1	0.372**	0.165**	0.094*	0.202**
(2) Self-organization in COVID-19	…	1	0.326**	0.618**	0.483**
(3) Environment	…	…	1	0.188**	0.279**
(4) Attitudes toward online classes	…	…	…	1	0.406**
(5) Communication	…	…	…	…	1

2. Questionnaire results

Student preference for synchronous courses was examined using a 4-point Likert-scale including 6 questions. As reported in Table IV, the Cronbach's alpha for the scale is 0.83 with a mean score of 2.86 ± 0.63 $(62.0 \pm 21.0)\%$.

To determine the relationships between the synchronous course preference and other variables (self-organization abilities, attitudes toward online courses, environment, and communication), Pearson's correlation coefficient was calculated. Table VII presents the correlation coefficients for each pair of variables. One can observe that students' preference for synchronous teaching formats correlates positively with their general self-organization abilities and negatively with their preference for online classes, which means that the students who prefer face-to-face classes tend to prefer synchronous teaching formats. Students with good general self-organization skills (in times of in-person classes) are likely to prefer synchronous classes because they help them in their organization in this new situation of e-learning, while the students with good self-organization skills during the COVID-19 pandemic show no correlation with the preference with the synchronous courses. One possible reason could be that well-organized students in the COVID-19 situation do not need synchronous classes in order to structure their day. There is also no correlation between the environment (quiet learning space) and the preference for the synchronous courses, suggesting that for our students that were not struggling with the prerequisites for attending video conferences, the technical and personal situation was not the main factor when thinking about the course format.

In addition, students were asked whether they like to learn from the recorded lecture videos, uploaded presentations, and lecture notes (which include asynchronous materials), and whether they like synchronous lectures. For each of those aspects, they were asked why they preferred or disliked a format. The results are presented in Fig. 2 and Tables VIII and IX, where students' preferences for a certain course format and the correlations between that preference and the main reasons for the preference are presented.

One can see that the attitude toward recorded lectures correlates positively with the possibility to learn at one's own pace, the possibility to pause a video, the perception of lectures as interesting, and the perception that they improve the understanding of the materials. As negative aspects, students recognized the missing possibility to ask questions, lack of communication, and they found them boring and not increasing their understanding. All correlation values are significant on the $p < 0.001$ level. This also

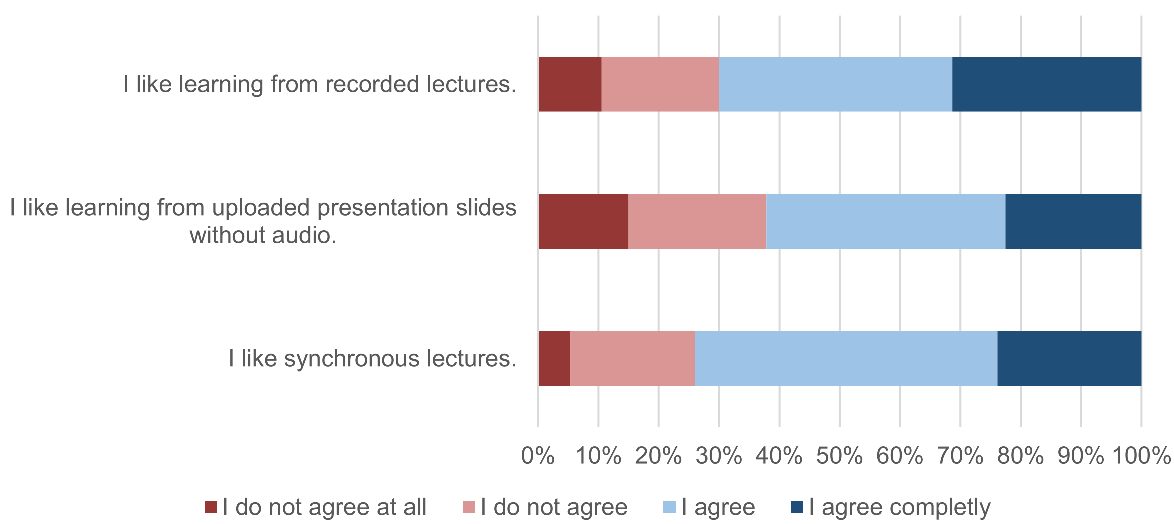

FIG. 2. Preferences for different course formats.

TABLE VIII. Correlations between attitudes toward asynchronous course formats (recorded lectures and uploaded lecture notes) and the reasons for that preference. All values are significant on the $p < 0.001$ level.

	Pausing the video	Accessibility	Learning at own pace	No possibility to ask questions	Hard to understand	Missing important information	Missing communication with other students	Concise information and fast learning	Boring	Interesting	Increases understanding	Does not increase understanding
Attitude towards recorded lectures	0.59	…	0.62	−0.37	…	…	−0.30	…	−0.49	0.40	0.45	−0.42
Attitude towards uploaded lecture notes (without audio)	…	0.50	0.50	−0.24	−0.46	−0.19	…	0.26	…	…	0.20	−0.29

TABLE IX. Correlations between attitudes toward synchronous lecture and the reasons for that preference. All values are significant on the $p < 0.001$ level.

	Overload schedule	Stressful	Fixed week schedule	Possibility to ask questions	Student centered	Teacher centered	Boring	Interesting	Increases understanding	Does not increase understanding
Attitude towards synchronous lecture	−0.34	−0.12	0.49	0.51	0.34	−0.15	−0.39	0.47	0.48	−0.38

corresponds to the results of the interviews. Students had the opportunity to write more comments about why they prefer or do not prefer a specific course format. Considering the uploaded lecture videos, students emphasized the flexibility of this course format: "*There are interesting technical possibilities, such as playing the video at a higher speed, at already known points or for repetition, which makes the time spent much more effective,*" but also reported having problems with concentration: "*Maintaining concentration is very difficult. Live lectures that are additionally recorded are best.*" One student wrote: *"I find a simultaneous lecture that is recorded optimal, so that you can ask questions directly, but also have time to look at more complex content again."*

When looking at results for synchronous lectures, the preference for this course format strongly correlates with having a fixed weekly schedule, the possibility to ask questions, interest in lectures, and increased understanding, while as negative factors student recognize an overloaded schedule, boring lectures, and not increased understanding. Additional comments in the questionnaire include the contact to other students (*"Even if only the names of the other participants are visible, it creates a sense of community"),* the anonymity that makes it easier to ask

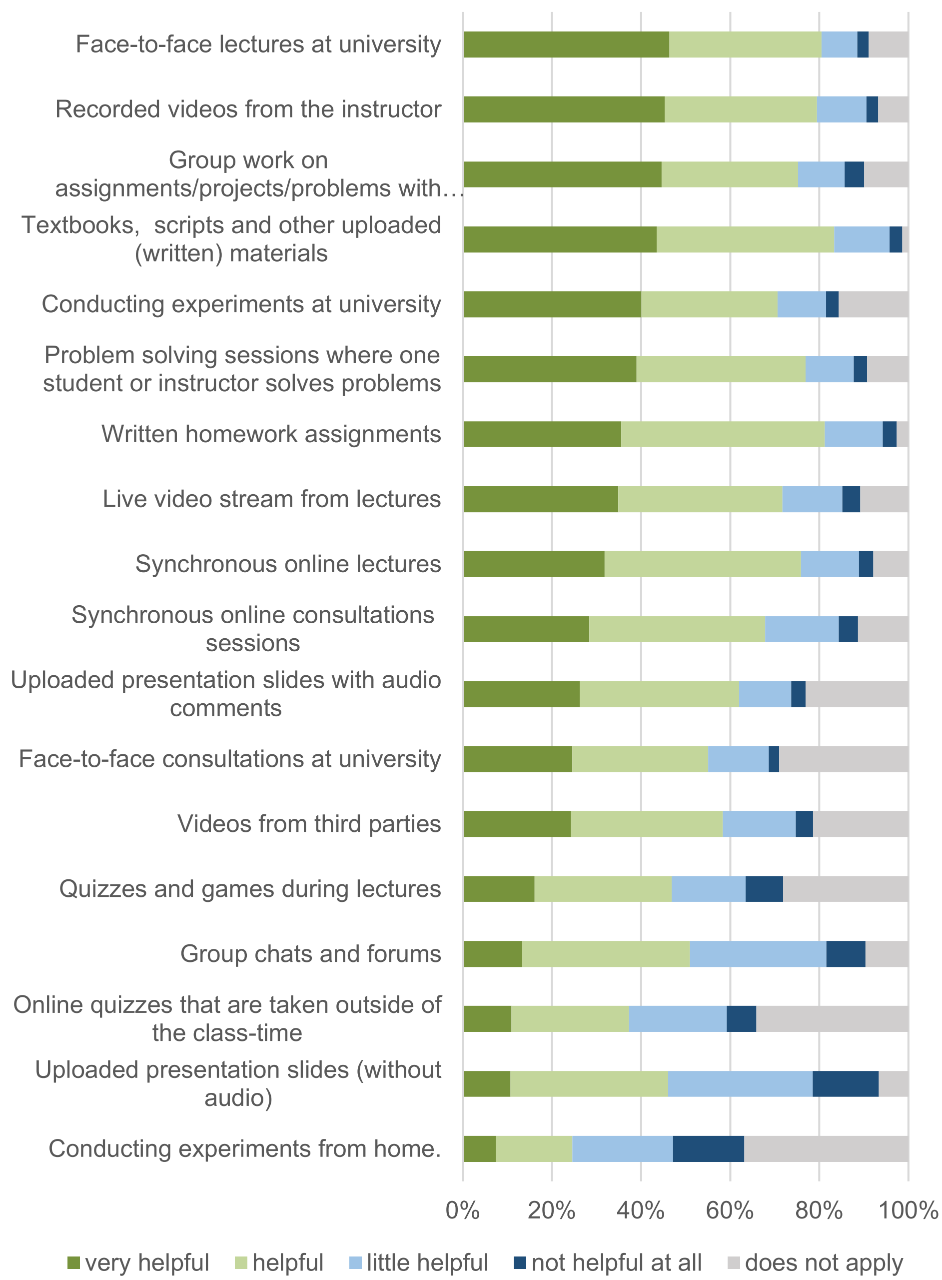

FIG. 3. Helpfulness of different course elements.

TABLE X. Course elements that are perceived to be helpful: Comparison between students with a high and low preference for synchronous or simultaneous courses (generated from a *post-hoc* quantile split).

	Quantil descriptives (M. SD)				Quantil comparions (t test)	
	High quantile ($N = 70$–115)		Low quantile ($N = 77$–124)		p	Cohen's d
Uploaded presentation slides (no audio)	2.62	0.98	2.45	0.94	0.19	…
Uploaded presentation slides (with audio)	2.01	0.90	1.90	0.82	0.39	…
Textbooks, scripts and other uploaded materials	1.73	0.81	1.59	0.81	0.18	…
Live video streams of lectures	1.41	0.64	2.30	0.94	0.00	−1.11
Recorded videos	1.81	0.82	1.58	0.73	0.03	0.29
Third party videos	1.93	0.82	1.91	0.86	0.87	…
Written homework	1.55	0.71	1.94	0.79	0.00	−0.52
Online tests to be taken outside of class time	2.18	0.86	2.62	0.92	0.00	−0.49
Tests and quizzes during lectures	1.89	0.88	2.81	0.96	0.00	−1.00
Tutorials in which a student or instructor solves problems	1.43	0.60	2.07	0.93	0.00	−0.82
Group chats and forums	2.24	0.89	2.45	0.88	0.08	…
Simultaneous online lectures	1.28	0.45	2.56	0.82	0.00	−1.93
Simultaneous online consultation or question time	1.65	0.75	2.50	0.87	0.00	−1.04
Conducting experiments at university	1.61	0.69	1.86	0.92	0.03	−0.30
Conducting experiments from home	2.54	1.00	2.91	0.81	0.02	−0.40
Live lectures at university	1.35	0.67	1.91	0.88	0.00	−0.72
Group work with other students	1.49	0.70	1.94	0.99	0.00	−0.52
Personal consultations on-campus	1.76	0.76	2.07	0.90	0.02	−0.37

questions, and a need for interactivity (*"I would like it if there were more questions and interactions, as this increases my attention significantly, and otherwise I find it very difficult to concentrate for so long at home").*

C. Helpfulness of different course elements

Based on the student interviews and the personal experiences of the authors, 17 different course elements were identified that could be assessed by the students in terms of the perceived helpfulness for learning. These include both synchronous and asynchronous online elements, as well as in-person course elements. Figure 3 represents the ranking of different course elements according to helpfulness for the learning and does not apply accounts for the course elements that were not experienced by students. Students perceived the face-to-face lectures at university as most helpful, followed by the recorded lectures from the instructor and the group work on the assignments, projects, and problems with other students.

As the least helpful activities, students listed conducting experiments at home, uploaded presentation slides without audio, and online quizzes taken outside of the class time. However, almost 40% of the students who responded to the questionnaire had no experience with conducting experiments at home and with quizzes and games, which influenced the ranking of these course elements for helpfulness.

To check whether the perceived helpfulness varied with students' preference for asynchronous and synchronous course elements, a quantile split was performed, and the results are reported in Table X. The table shows the item means and standard deviations in the upper and lower quantiles regarding the students' preferences for synchronous courses. Students in the upper quantile show a stronger preference for synchronous courses. The items list course elements, and students had to indicate how helpful they felt each element was for learning using a Likert scale from 1 to 4 (with low values referring to strong agreement, i.e., high perceived helpfulness). The lower the mean value in the Table X, the higher is the perceived helpfulness. For example, high quantile students (strong preference for synchronous courses) find live video streams of lectures much more helpful (mean 1.41) than low quantile students (preference for asynchronous courses, mean 2.30). Oppositely the low quantile students find recorded video to be more helpful (mean 1.58) than high quantile students. The variation in the quantile size is due to missing values of those students for whom the respective item did not matter (because the course element was not present).

The results suggest that students who preferred synchronous course formats found live video streams of lectures, synchronous lectures, and synchronous consultations more helpful than their colleagues who preferred asynchronous course formats. Moreover, they also found the course formats that are held in person in the classroom as more helpful, for example, live lectures at university, tests and quizzes during lectures, group work, and tutorials. There is no significant difference in perceived helpfulness of uploaded materials and presentation slides in learning

TABLE XI. Course elements from the COVID-19 semester that students would like to preserve in the future.

Course elements	Examples of students' responses	Frequency
Making course material available through learning platforms	*"So, I think it's very nice that people are using OPAL (learning platform) more actively now. And I know that many people are a bit ambivalent about OPAL, but basically, I find it quite practical. And I would like to see this maintained in the future as it is now. In other words, that all the materials that are relevant for the course are always available." [TUD02]*	7
Uploaded lecture videos	*"Yes, one thing I can think of is lecture videos being uploaded. … But I don't think that this should replace a classroom lecture, but if they are simply offered in addition, I think that would be totally good." [UG03]*	6
Nothing	*"So, in principle, if face-to-face courses are offered again, I want to be present at the university, because I study at a face-to-face university and not at an online or distance-learning university. That's why I prefer presence only." [TUD03]*	4
Online question and answer session	*"Maybe an online Q&A session, I would find that quite exciting, because that's not mandatory, and one may skip that. You just don't go because it's not mandatory, but it would be good if you go. If it were offered online, it would be much easier in terms of distance … And it would be easily accessible from anywhere, and that would often be very exciting." [UV03]*	3
Use of forums for asking questions	*"In any case, a forum, in general, a question forum, because there are students who are perhaps somewhat shy and do not dare to ask questions or write an email or something like that. Or who might need time to thaw out a bit and then dare to ask questions sometime later." [UV03]*	2

plattforms, group chats and forums, and videos of third parties.

D. Implications for future physics courses

To identify implications for future physics courses, students were asked which online course elements they would like to preserve, even when the COVID-19 pandemic is over and regular university classes are possible. Table XI summarizes the results from the interviews and Table XII the results from the questionnaire. Results from the questionnaire are split according to the different universities to show that they are consistent across different institutions.

Seven interviewed students expressed the desire that lecturers continue using the learning platforms and continue uploading the materials relevant to the courses. This was confirmed by the questionnaire results where about 90% of all students (varying from 78% at TU Kaiserslautern to 97% at TU Dresden) have selected that they want to preserve it in the future. It was followed by the uploaded lecture videos both from the interviewed students as well as from the results of the questionnaire. Four of the students interviewed expressed that they do not want to preserve anything because they preferred presence only. Other mentioned elements that students would like to see in the future are online consultations (instructors' weekly office hours), discussion forums, and recorded videos of lectures as a replacement for classroom lectures.

V. DISCUSSION

A. Synchronous and asynchronous course formats

Students' perception of synchronous and asynchronous course elements was assessed both through interviews and questionnaire. Regarding the first research question of

TABLE XII. Elements that students want to preserve in the future—results from questionnaire.

	Learning materials uploaded in the learning platforms (scripts)	Recorded video of the lectures in addition to classroom lectures	Synchronous online consultations in addition to classroom lectures	Recorded video of the lecture as a replacement for classroom lectures	Synchronous online lectures in addition to classroom lectures	Conducting experiments at home as a replacement for some lab experiments	Synchronous online lectures as a replacement for classroom lectures
Dresden	97%	73%	48%	26%	22%	15%	13%
Göttingen	93%	78%	31%	18%	22%	9%	9%
Vienna	92%	76%	49%	26%	39%	23%	27%
Kaiserslautern	78%	67%	33%	11%	22%	0%	22%
Zagreb	89%	76%	46%	14%	27%	20%	13%

which course formats students prefer and why, it is not possible to give a clear answer. According to students in this study, each course format has its advantages, and the preference for the course formats correlates with students' self-organization skills and their preference for online or face-to-face physics courses. Results from the interviews indicate that more students prefer synchronous courses and that they see more advantages than for asynchronous courses. The possibility to immediately ask questions, the feeling of community, and the fixed daily structure were mentioned as the main advantages of synchronous courses, while flexible time management, the possibility to watch videos at their own pace, and to concentrate better were the main advantages of asynchronous courses. These results support the model of Hrastinski that synchronous courses increase motivation, support other types of communications, and monitor learners' response to the content, while asynchronous courses support cognitive engagement and content-related communication [25]. While Hrastinski based his model on the classification of sentences during synchronous and asynchronous seminar discussions in the field of management, this study focuses on physics students' preferences for specific course formats as well as the advantages and disadvantages of synchronous and asynchronous courses from the students' perspective. In addition, the students participating in this study did not voluntarily decide to take part in online courses but were forced into an e-learning setting through the COVID-19 pandemic. Figure 4 represents the summary of the advantages of synchronous and asynchronous course formats. Both formats build the pillars for the successful completion of (online) physics studies and the acquisition of competencies to become a physicist or physics teacher. As the students interviewed mentioned that a good balance between both formats is crucial, and together they contribute to cognitive and personal engagement that are both important for the successful completion of the studies. This is in agreement with the conclusions from Hrastinski [25] that synchronous and asynchronous course formats support each other. Clear learning goals, basic technical prerequisites available to students, and technological-pedagogical-content knowledge [54] of the instructors are the foundations for both formats to be implemented successfully.

The correlations between the preference for synchronous courses and other aspects of e-learning suggest that students who have more positive attitudes towards online courses also prefer asynchronous course formats, and students with positive attitudes towards face-to-face courses prefer synchronous formats. Although all participating universities are face-to-face universities, one needs to be aware of different preferences, technical prerequisites, and self-organization skills of the students and to take these into account when planning the future courses to make them accessible for a great variety of students. Furthermore, our recommendation is to use the synchronous online course formats and face-to-face synchronous courses for discussions, cognitive activation of students, and for question-and-answer sessions, while the asynchronous course formats with the self-learning phases are more suitable for deepening the knowledge.

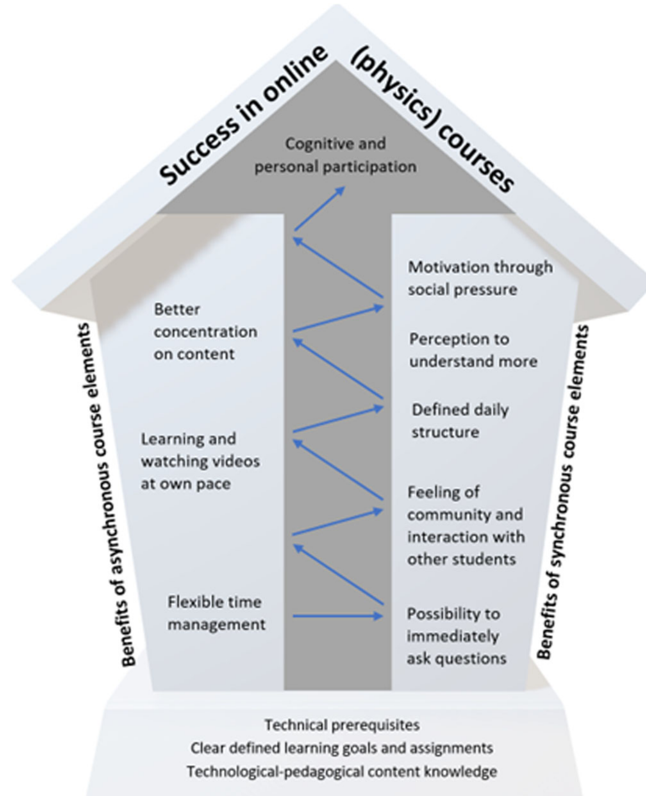

FIG. 4. Model for use of synchronous and asynchronous course formats. The pillars represent the benefits of asynchronous and synchronous course formats that lead to success in online (physics) courses. The arrows represent the interconnection between these formats and a need that they go together and supplement each other.

B. Helpfulness of different course elements

Regarding the second research question, which course elements students found helpful, we can conclude that the students in our study found face-to-face lectures at the university to be most helpful, followed by recorded lecture videos. Group work on the assignments and projects is also found to be very helpful for learning according to the students, which is consistent with the results reported in our previous paper, where students were less interested in handouts with the complete solutions of recitation problems, but wanted to work together live on exercise sheets [44]. The quantile split based on the student preference for synchronous and asynchronous course formats indicates that their perception of the helpfulness of different course formats for their learning is influenced by their preference for synchronous or asynchronous courses. Students with the preference for synchronous courses find all synchronous course elements more helpful, as well as the face-to-face course elements. Although perceived helpfulness may differ from the actual helpfulness and performance in the physics courses, it is still important to consider the course elements that students find most helpful.

C. Implications for future physics courses

The majority of students interviewed, as well as the students who took part in the questionnaire, would like to have uploaded course materials and recorded lecture videos available in the learning platforms in the future (post pandemic). Klumpp *et al.* observed the same phenomenon in their reflection on COVID-19–induced online teaching in biophysics courses [55]. They found that despite their wish for lecture recordings, students still value synchronous live lectures (as measured by attendance), even under conditions of online teaching, and that a majority of students attended live lectures and a minority chose to use videos exclusively. In our study, 67%–78% of students would like recorded lectures to continue to be offered in addition to classroom lectures, while only 11%–26% of students would like them to replace classroom lectures. As Lindsay and Evans found in their review of the use of lecture capture in university mathematics education, their impact on student learning and attainment is not clear [19]. We are aware that making the recorded lectures to students available is connected with the possible drop of the course attendance and, in this case, possibly poorer performance, but according to the statements of the students in our study, we believe that if live lectures are interactive, that is when students have the opportunity to ask questions, involve in group discussions about the physics concepts and answer the conceptual clicker questions, that they would still prefer to actively attend the live classroom lectures and use the lecture recordings to deepen their knowledge and revisit more complex content. That corresponds to the results from Wood *et al.* [20] who found that students preferred to attend live lectures in a flipped classroom setting when they feel that attendance in live lectures has some discernible additional benefit. However, the connection between the availability of recorded lectures and the postpandemic course attendance as well as the course performance are still to be investigated in more detail.

Another element that students would like to have after the pandemic are synchronous online consultations (31%–48% of the students in our study). This could make it easier for students who cannot spend the whole day at university due to work, taking care of a family member, or their health to ask questions and keep pace with their course work. However, it is important that these synchronous consultations accompany synchronous or in person course formats in order to prevent skipping office hours and falling behind. Doucette *et al.* reported previously that students getting no incentives to keep up with lecture videos and homework most students in asynchronous classes skipped office hours [41].

VI. CONCLUSION AND RECOMMENDATIONS FOR THE FUTURE COURSES

In this and our previous study [44], eighteen students from five European universities were interviewed and 578 students were assessed using the questionnaire containing 246 technical data fields which were divided into 13 subtopics to obtain information about students' perception of online physics courses and to draw lessons for the future. While our previous study reported on online problem-solving sessions, online physics laboratories, and factors influencing subjective learning outcomes [44], here we reported the results on students' preference for synchronous and asynchronous activities in physics courses, the main advantages and disadvantages of both course formats, which course elements students perceived as helpful to their learning, and which course elements they would like to have after the pandemic. Students reported positive and negative aspects of both synchronous and asynchronous course formats. The most common reported advantages of synchronous course elements were the possibility to immediately ask questions, feeling of community and interaction with other students, and defined daily structure, whereas the most common advantages of asynchronous course elements were flexible time management and the possibility to watch videos at their own pace.

The data indicate a correlation between preference for synchronous courses and their general self-organization, so instructors should be aware of this connection when planning future courses. Furthermore, our results suggest that most students would like to preserve in the future uploading of learning materials and recorded video of the lectures in addition to classroom lectures. Overall, the results of this study suggest that both synchronous and asynchronous course elements should be combined in future online and in-person physics courses.

Our findings suggest the existence of two groups of students: one group with the clear preference for synchronous physics courses and the other group for the asynchronous courses. This preference is influenced by their self-organization and preference for online or face-to-face courses. Before the COVID-19 pandemic, most academics were not aware of the different needs of these different groups of students.

When taking into account all elements from our interviews and questionnaire, including preference for synchronous and asynchronous physics courses, helpfulness for learning and the student wishes for future physics courses, we can summarize a few recommendations for the future online and in-person physics courses:

(i) Formulate assignments and learning goals for the course as clear as possible.

(ii) Use synchronous course formats (online or in classroom) to cognitively activate students and engage them in discussions using quizzes, group problem-solving sessions, group discussions, tutorials, and group projects. Digital boards can be used to collect group results and monitor group progress.

(iii) Provide collaboration tools for students to exchange their ideas or ask questions.

(iv) Use asynchronous course formats to expose students to more complex content. Upload relevant information to learning platforms to make them available for all students and to provide them with the same opportunities for learning. In order to increase student engagement with asynchronous course formats consider giving incentives for completing asynchronous tasks [41,56].

(v) Ensure a good balance between synchronous and asynchronous course activities. Supplement live lectures with the lecture recordings to make them available to students after the lectures or even before if you are using flipped classroom methods.

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