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Post-COVID-19 Student and Faculty Perceptions of Online Computing Labs: Better Targeted, Better Perceptions, but Still Need Improvement

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Abstract: In many disciplines, the growth of online courses was propelled by the COVID-19 pandemic, but this trend moderated as health concerns receded. Before the pandemic, computer science-related disciplines were less keen on online labs because of their inherently hands-on nature. This study presents a comparative analysis of student and faculty perceptions towards online labs in three computing-related disciplines a year after the pandemic. Through a survey with 242 students and 20 faculty responses, we found students were, overall, positive about their online lab experience—as were faculty. Students and instructors both agree that (1) where provided, online lab courses are being taught effectively, and (2) it is crucial to continue investing in technology infrastructure to enhance the quality and accessibility of both online and in-person labs. However, students and instructors disagree on two issues: (1) teamwork for lab activities and assignments (i.e., faculty tended to have a more optimistic view of online collaborative activities); and (2) modality for lab sessions (i.e., student preferences were evenly split between synchronous and asynchronous labs while faculty mostly preferred synchronous online labs). Faculty appear more optimistic about the effectiveness of online labs but show heightened concern regarding technological disruptions. Notably, all comments from students asserted the importance of having recorded demonstrations, even when a live synchronous demonstration may have been provided. Utilizing recordings and making them available is an example of a best practice worth promoting despite the added effort for faculty.

Keywords: online learning; computer science laboratory; faculty perception; comparative survey

1. Introduction

There has been a growing interest in online computer science courses, and the COVID-19 pandemic has temporarily expanded this growth. The primary challenge in remote learning for computing-related courses is their lab component, which often involves specialized software and/or hardware, team-based collaboration, and a complex array of activities. In this paper, we report our findings from both students' and faculty's perspectives regarding their online lab post-pandemic experiences. Specifically, we are interested in three questions. (1) Currently, what are the key factors that impact online lab student learning, especially those that continue to be problematic? (2) What are the differences between students' and faculty's opinions regarding lab learning? And (3) w hat are the best practices for enhancing the lab learning experience at this point in online lab evolution?

2. Literature Review

To organize our literature review and structure our questions for this study, we relied on Van Wart and colleagues' study of online best practices [1] based on the Venkatesh et al. model of technology acceptance (the Unified Theory of Acceptance and Use of Technology or UTAUT) [2]. The UTAUT model focused on factors leading to adoption based on performance expectancy, effort expectancy, social influence, facilitating conditions, experience, and voluntariness of use. Adapting the model to a best-practice perspective, five major variables were identified as particularly significant. The overall acceptance and performance of online teaching, of labs in this case, is essentially the dependent variable. The independent variables of adoption and best practices include high-quality instructional design and delivery, reasonable effort expectancy, opportunities for interaction and collaboration, and adequate technological proficiency and access. Each of the five major variables is discussed below with regard to what we know about them in the context of online labs in STEM- and computer science-related disciplines.

(1) ***Overall Acceptance and Performance*** is a variable that captures the broader trend in attitudes towards online labs, both in terms of general acceptance and perceived performance. Researchers have used questions related to effectiveness, perceived quality, learning achievement, and satisfaction to capture various dimensions of student and faculty overall perceptions.

A commonly discussed issue is the comparison to and integration of face-to-face with online methods. The general effectiveness of virtual labs in STEM and computer science courses with robust faculty support has long been established. Well taught and appropriately situated online labs can be a roughly equivalent learning experience. Some researchers have noted that mixed modalities in terms of in-person and online can glean the best of the respective modalities [3,4]. For example, in a literature review of the strengths and weaknesses of virtual labs, Wahyudi et al. note that because of challenges such as limited interactivity, restricted content, and technical issues, more use of online labs as supplemental rather than primary modes may be best practice in many cases. Bhagyavati and Wolf [5,6] provided early examples of successful online labs in computer science courses. Some successful recent examples have included programming [7,8], computer hardware [9], and microcontrollers [10]. Lynch [11] pointed to ongoing software advances making virtual labs more powerful and flexible which has included haptics (e.g., embedding haptic sensors in 3D virtual reality for a better understanding of real-world objects [12]) and the selective use of animated graphic learning materials—where the critical mass of use justifies the effort and expense—to enhance motivation [13]. However, researchers in computer science frequently take note of the variety of circumstances—and challenges—by course [14], and literature reviews have also pointed out that some disciplines, such as physics [15], seem to have a more propitious environment than others, such as chemistry [3]. Researchers have been particularly positive about the utility of virtual labs as tools aiding collaboration [16] and gamification [14,17]. Nonetheless, challenges remain significant in various areas and aspects, such as implementing simulators and virtual reality [18,19] without technical difficulties, as well as in ensuring that novice student users are not overwhelmed [20] and self-efficacy is enhanced rather than having students feel like "they are learning on their own" [13,21,22]. The rapid transition to online labs during the COVID-19 period was also noted as a major challenge [23,24]. As Glassey and Magalhães [25] note, virtual labs are here to stay as an important part of the STEM course lab landscape. To get a sense of the level of post-COVID-19 acceptance, we asked to what degree virtual labs assisted with learning goals, and then asked about virtual labs' effectiveness in general compared to face-to-face labs.

(2) ***Instructional Design and Delivery*** is a variable which analyzes specific aspects of the quality and organization of the instructional material and modalities (e.g., how it

is delivered such as in-person, online, or hybrid, and when it is convened such as in a simultaneous session or asynchronously at students' convenience) and delivery to ensure it supports diverse learning needs and preferences. Teaching lab classes is a particularly complex type of teaching because it embeds lecture, demonstration, applied exercises that are generally both cognitive and psychomotor, and feedback [26]. Complicating lab teaching in online settings is the challenge of embedding complex exercises in virtual environments. For example, Jurc, Kontšek, and Šterbák [27] note that "each of these [virtual labs] provides several unique functions, but none of the above options [alone] will replace all the processes needed to replace a physical laboratory". Ultimately, instructors must consider and balance a variety of design factors such as: cost, scalability, feedback to students, assessment transparency, hands-on experience, student engagement, and assessment integrity [28]. There are a number of major decisions faculty must make in moving to partial or full online labs; one is whether an online lab will be virtual or remote [28–30]—that is, will the online lab be conducted virtually on students' computers through programs the university provides or the student acquires, or will the student remotely log into a campus-based lab utilizing physical equipment or joining a physical campus-based session with an instructor. A second consideration is the complexity of the lab [29–31]. Most online computer science "hands-on" sessions have traditionally been "problem and practice labs" which provide an opportunity for students to work through exercises, individual or group cases, or scenarios. There seems to be a trend toward more complex labs focusing on simulations which are becoming ever more sophisticated [12,13]. To cope with the complexity of online labs, many instructors turn to free and proprietary suites of lab exercises and simulations such as CloudLabs Learning, KodeKloud, Penn Engineering Virtual Lab, CloudShare, Nova Labs, and Instruqt. Another major decision that some faculty take up before going online is flipping the classroom in various ways to increase active learning, but which becomes even more pronounced in transitioning to an online environment [14,32–34]. Elmoazen et al. pointed out the need for a good grasp of learning analytics to take advantage of the online environment [35]. Because of the demands and new skills that instructors must acquire, Servin, Pagel and Webb [36] pointed out the need for specialized training for competence and consistency. Students' perceptions of how effective online labs are for them overall, which includes factors that may have little to do with the instructional design itself, is investigated under overall acceptance and performance. Since students are also sensitive to the time and energy an instructor devotes to instructional design and delivery [5,37], we ask students to evaluate their instructors' design effort as an indicator of this dimension.

A particularly critical issue is about the interest of students and faculty preferences for synchronous versus asynchronous labs (i.e., having a set time for labs versus letting students complete their labs at a time of their choosing) [38]. Synchronous labs offer a sense of learning community, opportunity for spontaneous questions with the responses being heard by all students, real-time monitoring, and the opportunity for faculty to adjust teaching in real-time depending on the lab progress [39,40]. However, asynchronous labs have many features to commend them as well. Of course, flexibility and convenience are maximized. Also, because many lab exercises and experiments take different amounts of time to complete or conduct, asynchronous labs can follow an "as-long-as-it-takes" strategy which in some cases may actually be less than a regular lab session. The various steps and progress can sometimes be better monitored in an asynchronous environment through learning analytics [35]. One study at the beginning of the pandemic noted that students were almost perfectly split in a bimodal pattern (43% to 45%) with few students expressing a "no difference" preference [41]. Students' preferences for a synchronous mode valued instructor interaction and travel convenience (as opposed to face-to-face labs) but noted environmental distractions in their viewing environment as a negative, e.g., [34]. In the obverse, students' preferences for asynchronous teaching appreciated that it was self-paced, easy to review for, and temporally convenient, but noted the lack of instant feedback as a major detractor [40]. This study revisits the synchronous versus asynchronous preference in a post-COVID-19 teaching environment.

(3) ***Effort Expectancy*** constitutes a factor which studies the amount of effort students expect to invest in order to perform well in the online lab course, or that faculty need to design and teach classes. In terms of students, much of the effort is in getting used to an online environment and once that is accomplished, the likelihood of taking additional courses increases [1]. Thus, since online labs strive for equivalency with face-to-face labs, effort is rarely a significant issue for students [29]. However, faculty effort is a major concern in most online settings. In an empirically based examination of engineering courses, Worley and Tesdell [42] found faculty spend about 20% more time building and maintaining online courses than face-to-face courses. In a large, multidisciplinary study, Dumont et al. [43] found that approximately 95% of all faculty felt the initial set-up was significantly greater for online courses, that 74% found it still was more effort the second time the course was taught, and that only slightly over half of the faculty respondents found it worth it. Faculty effort, specifically in building and maintaining labs, has not been gauged related to computer science in the past. Our question, therefore, focuses on faculty concerns about effort. It asks faculty about additional preparation and teaching time associated with online teaching.

(4) ***Interaction and Collaboration*** is a factor which considers the quality of interactions with student peers and how social aspects influence students' online learning experience and team-based project assignments. It is sometimes called "social presence" and focuses on the quality of shared learning and collaboration among students, such as in threaded discussion responses [44,45]. In the general literature, while some studies found social presence or related concepts to be significant (e.g., [46–48]), others found social presence to be a small or insignificant factor in learning [49,50]. In the virtual lab literature related to collaboration in computer science and engineering courses, three studies with small N's have supported the value of collaborative models to improve learning outcomes. Hwang, Kongcharoen, and Ghinea set up a small experimental design in the context of an Information Technology and Computer Science course, finding the experimental group "significantly outperformed" the control group and were more satisfied with the learning experience [16]. Konak and Bartolacci [51] did a study in the context of an introductory level database class finding that students in the collaborative version benefited more than students who completed the lab on their own with respect to their learning and attitudes towards the subject areas. Van den Beemt et al. [22] used systems and control courses in engineering, finding teamwork supporting peer learning and discussion to be effective during their investigation of a number of active learning strategies. This study asks how important students and faculty think that "working together with other students is helpful for completing online lab activities and assignments".

(5) ***Technological Proficiency and Access*** is the final factor studied and evaluates both the availability of necessary technology and students' ability to effectively use them. An area of particular importance for students and faculty are technical problems because "glitches" cause delays, create confusion, consume time, and increase stress. The general online learning literature has consistently placed technology issues among the top concerns in online teaching [52]. While these matters became less concerning over time (e.g., [46]), they reemerged with the sudden transition to online learning during the pandemic (e.g., [53]). Aldwairi [54] notes that "students and instructors were inundated with technical problems, performance issues, connectivity, configurations and time issues". Ironically, few researchers have looked at this issue more recently in the virtual lab context. For example, Wagner, Myers and Konak [55] talked about technical problems and the slowness of machines but there has not been a direct inquiry into technical problems until the issue was raised again in the rapid transition to online learning. Somewhat obliquely, Hackett et al. [39] recommend a synchronous format to alleviate technical issues while providing superior didactic support. This study asks about the perceptions of student technology

challenges from both a student and faculty perspective. It also asks about a technology opportunity—recorded demonstration videos for lab classes.

3. Method

Students were recruited during Spring 2023 from a large public university in the Southwestern United States. Students were invited to participate via instructors in targeted departments. All faculty in the targeted departments were invited to participate by colleagues on the research team. A questionnaire was developed to examine broad experiences and perceptions in online courses. Within the full sample, there were 242 students and 20 faculty members (collected the same semester) with experience taking or teaching at least one online lab in the disciplines of interest.

The research study was approved by the university's Institutional Review Board and informed consent was obtained before data were collected from each participant. Both students and faculty were informed that the study was confidential and voluntary. All faculty respondents and some students (41.7%) were volunteers. Most student respondents (58.3%) were incentivized with extra credit, with a non-research alternative available.

The student sample included 139 responses from Computer Science and Engineering, 80 responses from Information and Decision Sciences, and 23 responses from Mathematics. These areas were selected to represent fields within STEM that have relatively large student populations at the sampled university. The recruitment process also prioritized departments that continued to regularly offer online courses post-pandemic. Most students (89.3%) were majoring in the targeted discipline and had substantial experience taking online classes within that discipline (mean = 5.1 classes; median = 4.0 classes; SD = 4.85). The majority of students (59.1%) had taken multiple online labs with an additional 34.7% having taken one online lab. It is worth noting that the student population is very diverse, with 63.2% from underrepresented minority groups, 59.5% being first-generation college students and 26.4% women.

The faculty sample included 10 responses from Computer Science, 8 responses from Information and Decision Sciences and Engineering, and 2 responses from Mathematics. Most of the faculty were tenure-track professors (60%), with 40% of the responses from lecturers. Most faculty were men (60%), with some women (25%) and several respondents declining to report their gender (15%). Half of the faculty participants reported that they did not belong to the underrepresented minority group, with 15% reporting a URM identity and 35% declining to respond. A larger number of faculty responded to the survey, but only those with experience teaching online labs were retained for the present study.

An open-ended question at the end of the survey provided an opportunity for comments that the survey participants wanted to make about labs. Seventy students made comments, but some were negligible (e.g., "nothing else"). However, some of the more substantive comments were multifaceted and divided, adding eight additional reflections to the pool. Three faculty made substantive comments for a total of 72 comments. Twenty comments discussed face-to-face versus online labs with the pros and cons of each of the two lab modalities being relatively balanced. Eleven comments referenced recording videos of instruction or demonstrations for labs; they were universally supportive of continued or more use of video in online labs as being a best practice. There were nine generic comments about labs that did not fit neatly into other categories or were not specific to online labs. There were nine comments about technical issues such as the preference for some of the software used in labs over others, or relating to some lab technical performance issues. There were also nine comments about faculty assistance. There was general agreement among the commentators that the quality of faculty effort and competence made a substantial difference in the online lab experience no matter the modality. There were six comments about collaboration in which there were mixed views expressed. There were five comments that discussed the pros and cons of synchronous versus asynchronous labs. While the comments are useful to gain insight into the empirical data collected, they are used here solely as auxiliary qualitative data to provide various perspectives rather than quantify them per se.

4. Results

4.1. Acceptance and Performance

Our survey included three questions to capture the broader trend in attitudes towards online labs. We asked participants whether they agreed that (1) online labs help to meet course learning goals, (2) labs can be effectively taught online, and (3) online labs can be as good as face-to-face labs. Students and faculty were asked the same or parallel questions for comparison. See Table 1.

Table 1. Student and faculty perceptions regarding online lab acceptance and performance.

Survey Question	Role	Mean *	Std. Deviation
Online labs help me [students/faculty] meet course learning goals.	Student	3.78	1.20
	Faculty	4.05	1.19
In general, labs can be taught effectively online.	Student	3.66	1.34
	Faculty	4.00	1.17
Online labs can be just as good as face-to-face labs.	Student	3.51	1.41
	Faculty	3.85	1.18

* 1 = strongly disagree; 5 = strongly agree.

The results indicated that the overall perceptions of online lab courses were positive related to all three questions to different degrees, and the views of students and faculty on these questions were consistent. Table 1 presents the descriptive statistics for each survey item in this factor on a 1–5 scale (1-strongly disagree to 5-strongly agree). It reveals faculty being generally more positive (an outcome that surprised us). The most general question about the helpfulness of online labs only had slight disagreement by 14.7% (disagree and strongly disagree) of student responses, as opposed to 61.5% who strongly or very strongly agreed about online labs helping achievement learning goals. When asked about teaching effectiveness, the negative student perceptions increased to 23.3%. When asked if online labs can be just as good as face-to-face labs, the negative perceptions increased to 27.9% and agree/strongly agree dropped to 56.3%. Nonetheless, the overall mean for students was still 3.51. Overall, 56.3–61.5% of students and 53.6–67.0% of faculty agreed that online labs can be taught effectively, are as good as face-to-face labs, and help students meet learning goals. Some notable findings are that (1) students with moderate to heavy family responsibilities have more positive responses to the questions and (2) the students who reported fewer positive attitudes tended to be first generation college students or those holding part-time jobs outside of school. There is a slightly higher rate of agreement among faculty members compared to students. This positive response is likely due to improvements in instructors' efforts in course preparation, teaching assistant support, and the accessibility of materials and software since the COVID-19 pandemic. This may also be partly because as recovery from the pandemic occurred, many labs were no longer offered online, therefore, leaving only those that are more suitable for online instruction.

In the open-ended questions, we asked students and faculty to comment on their experience with online labs. The comments were overwhelmingly positive. For example, one student noted the benefits of flexibility, saying, "Having no set time makes it easy for me to work and revisit notes and lectures". Effectiveness, however, hinged on instructor quality. A student summed it up: "It all depends on the professor. . . A good professor versus a lousy professor". While many positive comments emphasized that most lab work was already computer-based and could be easily done remotely, some negative feedback focused on the loss of hands-on interaction and instant instructor guidance. The sentiment was captured by one student: "Most CSE lab courses can be done effectively from home, however, there are some... that are much better in person".

In addition, some students viewed online learning as beneficial for their future careers. One student, who had experience as a software engineer, noted the relevance of remote work tools: "Most of our collaboration is done remotely via MS Teams. . .We share our code base over TSF. . . using remote technologies is commonplace for me and could be a good steppingstone". Another student pointed out the skills gained through online learning: "Online learning builds self-reliance, motivation, and determination, which are all incredibly important factors that help students transition to real-world jobs". In summary, online lab experiences have been largely positive, but the quality of the student experience remains closely linked to both the virtual adaptability of the particular lab materials and instructor effectiveness.

The data show a general consensus between students and faculty that online labs can be effective, but there was a greater level of optimism among faculty members. The higher rate of agreement among faculty compared to students may reflect a belief in their ability to deliver content effectively online. Despite a majority in favor, the mixed opinions highlight the need for ongoing evaluation and adaptation of online labs to ensure they meet educational objectives and student expectations.

4.2. Instructional Design and Delivery

To analyze the quality, flexibility, and organization of the online labs, our survey included two questions: (1) How do students rate the faculty's effort in preparing these labs? And (2) Which online lab modality is best for students' learning: synchronous or asynchronous? In our survey, "synchronous" online labs involved real-time, interactive sessions where students and instructors participate online simultaneously. In contrast, "asynchronous" online labs provided course materials, lectures, and assignments that students could access and complete at their own pace, without the need for real-time interaction. See Figures 1 and 2.

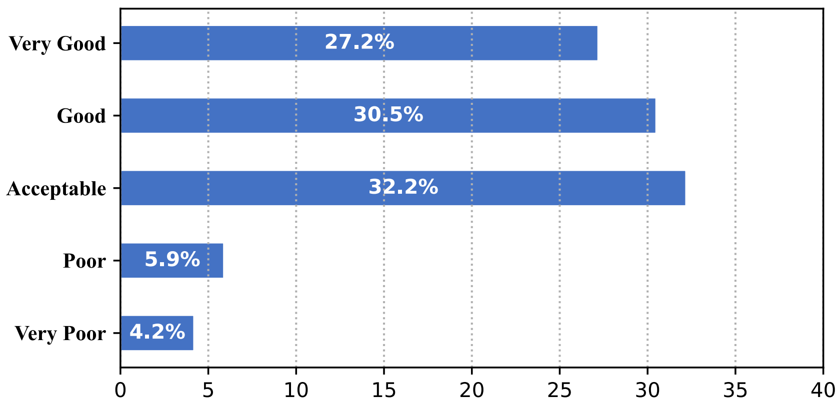

Figure 1. Students' perceptions of instructor effort. (Question to students: How would you rate the instructor's effort in preparing online labs?).

The results of the first question are shown in Figure 1, which identifies student perceptions regarding the effort they perceived that instructors put into online labs. Students predominantly rated the instructor's effort in preparing online labs as "Acceptable", "Good", or "Very Good", with these categories, collectively around 90% of the responses. This suggests that the majority of students are satisfied with the effort instructors put into online lab preparation.

The positive student feedback suggested that despite having to put forth the increased effort, faculty are succeeding in delivering quality online lab experiences. The data underscores the need for greater recognition and support for faculty who are putting in extra effort to adapt lab courses for online delivery.

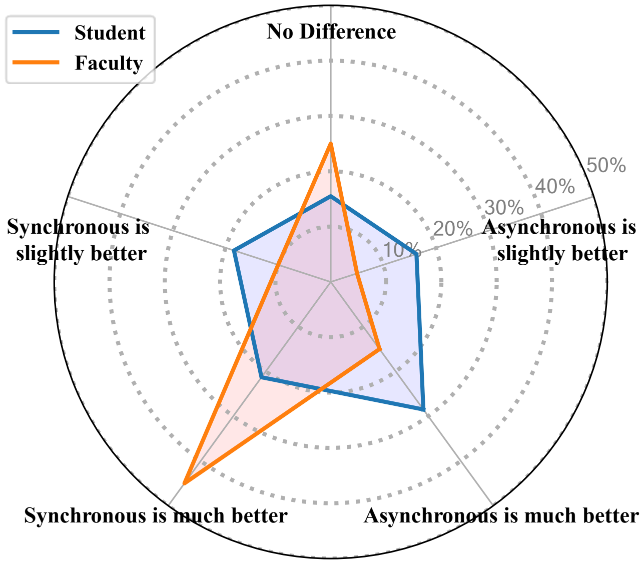

Figure 2. Student and faculty preferences for online labs. (Survey question: In online labs, which format is best for your [or student] learning?).

When considering preferences regarding online courses offered synchronously vs. asynchronously, student preferences were generally evenly divided, whereas faculty mostly preferred synchronous online labs. Figure 2 is a radar chart visualizing the combined opinions of students and faculty regarding the delivery mode. Each axis represents a category of opinion, and the distance from the center indicates the proportion of respondents in each category. The results show 55% of faculty believe synchronous labs are better for students' learning, compared to 39.7% of students. In contrast, only 20% of faculty believe asynchronous labs are better for learning, compared to 44.8% of students.

The data points to a clear preference difference between students and faculty. While students appear to favor the flexibility of asynchronous labs, faculty members emphasize the interactive nature of synchronous labs. This divergence in preferences underlines the importance of an approach that intentionally considers the strengths of both synchronous and asynchronous formats for the targeted student populations.

As to the open-ended questions, the preference for synchronous online lectures among faculty members may vary from course to course, but the commonly cited reasons are: (1) Simplified planning and execution: For faculty accustomed to in-person teaching, a synchronous online lab often adheres to a consistent schedule and might feel more natural; some faculty find it easier to manage a live, synchronous platform compared to juggling the various tools and platforms often required for effective asynchronous teaching. (2) Enhanced interaction and engagement: Synchronous settings allow for immediate questions, answers, and adjustments, helping faculty gauge student comprehension in real-time; it is easier to monitor student attendance and if they are actively participating in the course.

Despite a pronounced bimodal split, there were few direct comments about the effectiveness of the modes in the open-ended responses. More important than the synchronous–asynchronous modality was the ability to interact with the instructor in a timely way. In an asynchronous lab, that could be best done in a well-organized recorded lab video, but also by good preparation in the regular lab, or a special time when the instructor was available. Synchronous labs were good when focusing on the instructor's ability to answer questions (e.g., "it is harder to ask for help in online labs when it is synchronous") and coordinate the class effectively.

It is worth noting that regardless of the modality, both students and faculty found it useful to record lab sessions so that they could review the lab content afterward. A hybrid or flexible approach, which incorporates both synchronous and asynchronous elements, may offer a compromise that leverages the strengths of both modalities in some cases.

4.3. Effort Expectancy and Facilitating Conditions

In this section, we investigate the amount of support from instructors and teaching assistants that students receive in online lab courses, the perceptions of faculty regarding the level of assistance that students need relative to traditional, in-person laboratory settings, and the perceived effort by instructors in conducting online labs in comparison to in-person labs.

In Figure 3a,b we looked at two sides of an issue, first at student expectations of instructor support, and then at faculty perceptions about whether students needed more support in online labs than in face-to-face labs.

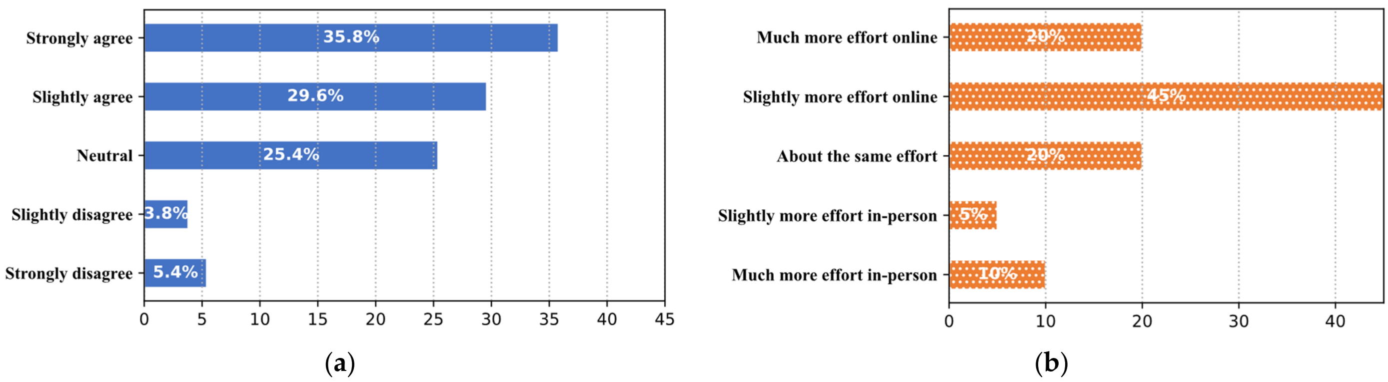

Figure 3. (**a**) Perceived levels of support received and needed by students (question to student: The instructor or teaching assistant supported me in online labs); (**b**) Faculty perceptions of student support needs in online versus in-person labs (question to faculty: How much support do students need in online labs compared to in-person labs?).

Figure 3a shows the student responses regarding their perceived support in online labs. Most students feel supported to some degree, with the majority either slightly or strongly agreeing (65.4% combined). The high percentage of students who agree (either slightly or strongly) suggests that the measures taken to support students in the online lab environment are effective. Figure 3b shows the faculty perspective on the level of support needed for students in online labs compared to in-person labs. A considerable majority of faculty believe that students need more support online, with 45% saying “Slightly more” and 20% saying “Much more”. This could be due to the technical challenges and lack of face-to-face interaction in an online setting, which might make it more difficult for students to understand the material or perform the necessary tasks without additional help.

In the qualitative results, almost all comments about instructor support ranged from “all instructors” to “most instructors” were good, e.g., “In my long-time experience of online learning I have found that definitively professors, on average, provide the most valuable, well put together, and compact content there is”. Nonetheless, perceptions of appropriate supportiveness were not universal. For example, one student pointed out a recent experience in which “we were kind of just guided by the book that was required for the course when our lab was online”.

As shown in Figure 4, faculty responses indicate a belief by many that there is an increased effort required for online labs. A significant 45% of the faculty reported that preparing online labs takes more effort than in-person labs, with 25% stating that it takes “much more effort online”. This viewpoint reflects the complexities and challenges faculty face when transitioning lab courses to an online format. Notably, 40% of the faculty felt that the effort is about the same, suggesting that a substantial portion of faculty may have adapted efficiently to the online mode.

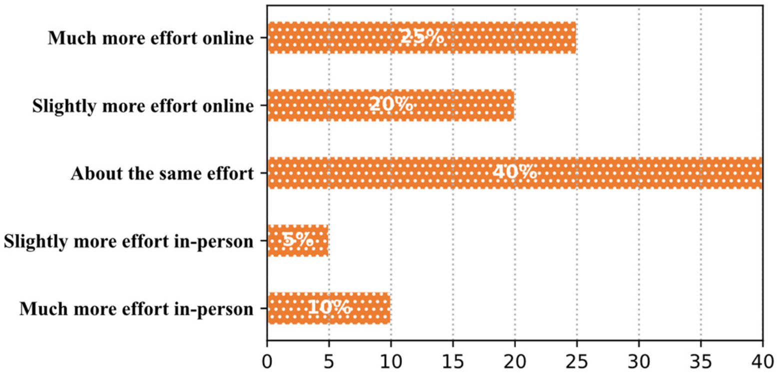

Figure 4. Faculty perceptions of the comparative effort levels of online and in-person labs. (Question to faculty: How much effort does it take to prepare online labs, compared to in-person labs?).

The results highlight the perceived adequacy of support from the student perspective but the anticipated need for additional support (i.e., more effort by instructors) as perceived by the faculty. Based on these results, institutions could consider providing additional training for instructors and teaching assistants to better support students remotely and developing more interactive and user-friendly online lab materials to aid self-learning and reduce the need for additional support.

4.4. Interaction and Collaboration

This section focuses on assessing the perceived value of student collaboration in online learning environments. The survey question (refer to Figure 5) aims to understand the role of peer interactions in the successful completion of online laboratory tasks, and how these interactions influence the overall learning experience and outcomes in team-based project assignments within an online context. Figure 5 illustrates the collective views of both students and faculty regarding the online collaborative assignments. Every axis on the chart corresponds to a different category of response, and the radial distance from the center reflects the percentage of respondents aligned with each specific category.

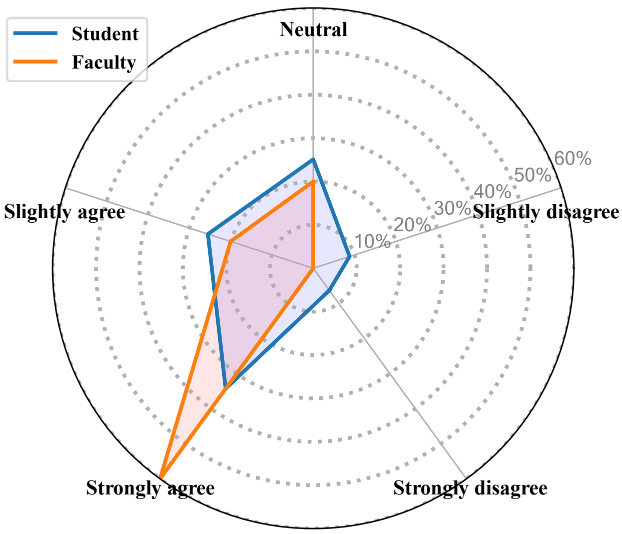

Figure 5. Student and faculty perceptions of the helpfulness of students working together. (Survey question: Working together with other students is helpful for completing online lab activities and assignments.)

It is a known challenge for group collaboration in online settings (e.g., [49,50]), so it was not surprising that *some* students felt that collaborative online lab activities and assignments are not helpful. This was the sentiment of 15.1% of survey respondents.

Interestingly, faculty tend to have a more optimistic view of online collaborative activities compared to the students. In our survey, 80% of faculty indicated that collaborative work is helpful for students, whereas only 59.8% of students felt the same way. This seems to indicate faculty may be optimistic about the efficacy of their teaching methods. Reconciling the differing views between faculty and students on the topic of online group collaboration may require a multifaceted approach, such as increased communication (e.g., faculty–student dialogue, asynchronous collaboration), and/or a revised group structure and guidelines (e.g., clearer expectations and rubrics).

The aspect of working together was little commented on in our survey. One student did note that "working in groups helped a lot" while another moaned, "please stop doing break out rooms".

The strong faculty endorsement of collaborative work highlights an educational value placed on peer interaction, likely rooted in the belief that it enhances learning outcomes and mirrors professional work environments. The student data shows a positive inclination towards collaboration but also reflects a greater diversity of opinions compared to faculty. This discrepancy could suggest a need for clearer demonstrations of the value of collaboration or could reflect the diverse nature of online lab work, where some tasks may benefit more from collaboration than others. Given the survey was conducted on various courses and majors, additional research could be conducted to understand the factors contributing to student reticence towards collaboration and address them through targeted interventions.

4.5. Technological Proficiency and Access

To evaluate the issue of technological proficiency and access in the context of online lab courses, we asked both students and faculty to respond to the statement "Problems accessing materials or software for labs have interfered with my [student] learning". The findings are shown in Figure 6.

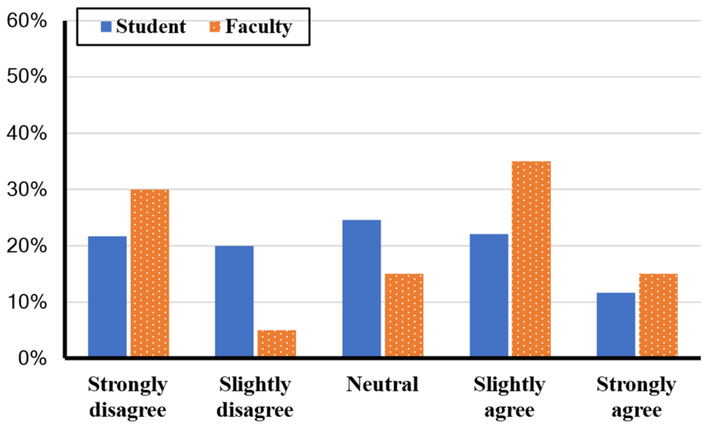

Figure 6. Student and faculty perceptions of lab access problems.

A majority of students indicated that they have not experienced outstanding issues, or the impact was not significant enough to sway their opinion strongly either way. However, a notable portion (33.8%) agreed that access problems have indeed interfered with their learning, indicating that for some students, technological issues are sometimes an obstacle. This difficulty of accessing software and materials for online labs is considered more challenging for Hispanic students than non-Hispanic students. Faculty opinions appeared to be more polarized. A total of 50% express agreement, with 35% slightly agreeing and 15% strongly agreeing that access issues interfere with learning on occasion, which highlights a perception that students are facing significant challenges. The disparity may be due to faculty being more aware of the challenges some students face, or having a broader view of the overall student experience, and being sensitive to any "glitches" that occur.

In the comments, some students reported that "the labs I have taken so far have all been online and have mostly been error-free and well done". However, when there were access problems, it was much more disconcerting to students. For example, "some things in Robotics were hard to access as an online lab". Another student commented that "I use Mac OS, and I have been required to use something that is only available for Windows OS, which meant I could not access it". Ironically, access problems also occur in face-to-face classes. One faculty member commented that "students deserve better technology support to access the lab workstations remotely. Accessibility to lab software and workstations remotely is declining dramatically". This was echoed by a student who said that he found the face-to-face "computer labs to [be] a bit under equipped", and who preferred his powerful personal computer in which he could actually get better access. Based on the feedback, it was clear that the institution needs to continue investing in technology infrastructure to enhance the quality and accessibility of both online and in-person labs.

These findings could also suggest the need for more robust technological support and resources to ensure all students have equal opportunities for learning. Further investigation into the specific technological barriers students face could help in developing more effective solutions. Training and resources could be provided not just for students, but also for faculty to better equip them to assist students facing technological access issues.

By far the most commented on aspect of online labs referred to recorded lab demonstrations. Remarkably, all comments asserted the importance of having recorded demonstrations, even when a synchronous demonstration may have been provided. One student said, "Labs are great online. I always have access to the videos for reference. I can pause the video if I need to. I can review labs before a test. It's effective". Another student said, "I believe if labs are constructed well and accompanied by a tutorial video or lecture, they are amazing online because there is no time limit, so you're able to work as long or as little as you want on the lab to complete it". One faculty member also commented that the "one thing I found that is helpful is to provide a walkthrough to help student get started on the lab and record it".

The survey results regarding the usefulness of recorded demonstration videos and tutorials in online labs are shown in Figure 7. There is a broad consensus among students that recorded materials are "very" to "extremely" useful. Faculty also overwhelmingly endorse the usefulness of recorded materials.

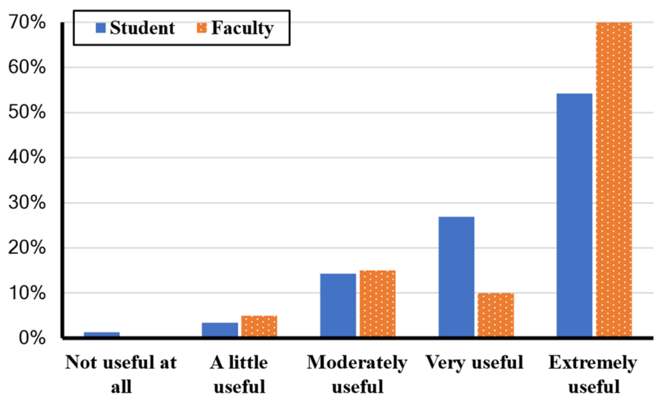

Figure 7. Student and faculty perceptions of the usefulness of recorded demonstrations and tutorials. (Survey questions: In online labs, how useful are recorded demonstration videos and tutorials?

The results underscored the importance of investing in high-quality recorded materials for online labs, as they are deemed significantly beneficial by both students and faculty. Faculty should continue to develop and refine their recorded demonstration videos and tutorials, ensuring they are clear, comprehensive, and pedagogically sound.

5. Results Summary

The major findings of this study are summarized in Table 2.

Table 2. Summary of top findings by research questions.

Research Questions	Question Items	Top Findings
R1: *What are the key factors that affect learning in online labs, especially those that continue to be problematic?*		
Subfactor #1: Acceptance and performance	• In general, labs can be taught effectively online.	Yes, labs can be effectively taught online.
	• Online labs can be just as good as face-to-face labs.	Yes, online labs can be as good.
	• Online labs help students meet course learning goals.	Yes, online labs help meet learning goals.
Subfactor #2: Infrastructure design and delivery	• (Students only) How do you rate the faculty's effort (design quality) in preparing these labs?	Students find faculty efforts acceptable to very good.
	• Which online lab modality is best for students' learning: synchronous or asynchronous?	Students think asynchronous is often good—primarily because of flexibility rather than achievement—but faculty don't necessarily agree.
Subfactor #3: Effort expectancy and facilitating conditions	• (Students only) The instructor or teaching assistant supported me in online labs.	Students thought that real-time support was acceptable to very good.
	• (Faculty only) How much effort is required for faculty to prepare an online lab?	Faculty thought online labs take more time; over a quarter responded they took much more time to prepare.
	• (Faculty only) How much support do students need in online labs, compared to in-person labs?	65% of faculty feel that students need much more support in online labs.
Subfactor #4: Interaction and collaboration	• Working together with other students is helpful for completing online lab activities and assignments.	Strongly advocated by faculty but only modestly supported by students.
Subfactor #5: Technological proficiency and access	• Problems accessing materials or software for labs has interfered with my learning. • In online labs, how useful are recorded demonstration videos and tutorials?	Students and faculty agree that on occasion technological issues interfere with learning, but faculty have a more bimodal distribution related to concerns. Online lab demonstrations are highly rated.

Table 2. *Cont.*

Research Questions	Question Items	Top Findings
R2: *What are the differences between students' and faculty's opinions on lab learning?*		
	• Which online lab modality is best for students' learning: synchronous or asynchronous? • Working together with other students is helpful for completing online lab activities and assignments. • Problems accessing materials or software for labs has interfered with my learning.	Students are more favorable toward asynchronous learning, while interest in student-to-student collaboration is strong, but a little less so for faculty. Students and faculty agree that on occasion technological issues interfere with learning, but faculty have a more bimodal distribution related to concerns.

6. Discussion

So how do the results from this study compare to the literature, keeping in mind that online learning has had an unusual trajectory because of the worldwide shutdown of most face-to-face learning for one to two years? In terms of the Venkatesh model, voluntariness dropped to zero, creating a rather bizarre situation in which students and faculty both experienced highly ambivalent feelings. On one hand, students and faculty were relieved to be in a safter situation, pleased that they could carry on the education function, and appreciative of the efforts made. On the other hand, many students lacked or were poorly trained for online learning, most found the exclusive use of online overwhelming, and they were especially nervous about the many inevitable glitches and errors that occurred in the rapid transition. Faculty, for their part, were generally shocked at the suddenness and breadth of the transition which occurred mid-semester for most, and most were unprepared for the range of knowledge and teaching skills required in short order. Then as the pandemic subsided, online requirements were generally removed rather swiftly (that is, voluntariness rebounded), and the number of online courses declined for several years, but the level of online course delivery is still significantly elevated beyond pre-pandemic levels [56]. Education experts tend to believe that online education will resume a positive trajectory for some time to come [57].

Performance and acceptance were modestly increasing in online labs in general, as well as computer labs up until the pandemic. While use briefly soared during the pandemic, average performance and satisfaction actually declined because of the sudden transition, inadequate resources, various psychological stresses from overuse to isolation, the forced enrollment of many opposed to taking or teaching online, etc. [34,38]. With the relative normalization of the education panoply of offerings, the increasing sophistication of online labs, and growing number of proprietary, public domain, and university-built options, positive perceptions might be expected to increase. Our study is an example of that expected trend with less than one third of students and one quarter of faculty believing that online learning in computer science labs cannot be as good as face-to-face. Of course, the caveat in the wording of the question is "can be", not "are". Those statistics would likely be less impressive if the reality, rather than the possibility, were assessed.

Course design and delivery is substantially more challenging for faculty on average (further discussed below), but do students appreciate the effort? Past research has indicated that students sometimes complain about "teaching themselves" in online courses and labs, a problem exacerbated by the pandemic [23,58]. Our study indicates that while students are very aware of faculty differences as the qualitative comments make clear, they are generally appreciative of the effort, with only a very small percentage being overtly critical of instructors' efforts. As for the asynchronous versus synchronous divide, which was bimodal in the past [38], the balance has not significantly changed.

We did not specifically look at student effort expectancy because it is well captured by performance. In the Venkatesh and colleagues' adoption model, effort expectancy is only substantial in the initial adoption phase when new knowledge and skills must be acquired. Since essentially all college students became adjusted during the pandemic, we did not investigate it. However, we were highly interested in examining effort expectancy for faculty since that has been a frequent concern by faculty, e.g., [42,43]. Not only did faculty feel that designing online labs was more time consuming than face-to-face labs, but they were more time consuming because students need more help. So this perception remains unchanged after the pandemic according to our sample.

We noted that the literature is mixed on the degree to which student collaboration is necessary for quality education, a critical aspect of active learning, a useful subordinate strategy, or not particularly important in many educational contexts, e.g., [22,24–29]. In this study, faculty were highly supportive of paired and group methods in conducting online labs, as were students, but slightly less so. Although one student expressed negativity in the open lab question, it may be that s/he was complaining about breakout sessions in lectures, rather than buddy or team procedures in labs.

Technological concerns had been reported as less critical leading up to the pandemic, only to be a resurgent problem in the pandemic [24,30,32,54]. When asked in this study if problems accessing materials or software for labs have interfered with student learning, only a third of the students expressed strong—if occasional—issues, compared to two thirds of the faculty. Of course, faculty are aware of any students who have technical issues in a class, as well as having the concern of ever-changing software and technology.

Additionally, we consider: what are the best practices learned from this study for enhancing the lab learning experience at this point in online lab evolution (research question #3)?

- Performance: Be aware that effectiveness can be high in many, and perhaps most, online computer lab situations today, but they are not without their challenges. Standard problem-and-practice labs have become routine using instructor-designed, department-designed, open source, and proprietary resources. However, the quality of the online lab resource software is very important. Investigating options, implementing more sophisticated lab activities, and monitoring online labs often takes extra effort by faculty;
- Design: Departments should provide some synchronous lab opportunities for student convenience wherever possible and in which lab monitoring by instructors or lab assistants is possible. However, departments should be aware that asynchronous courses take a lot of specialized design features to ensure a robust experience. Weaker and less motivated (or simply distracted) students can easily get lost or behind without tight scaffolding, highly detailed instructions, frequent activity deadlines, formative assessments, individualized and personalized support, and the like;
- Effort expectancy: It is very important to select faculty to teach online labs who support their efficacy and who are willing to ensure that they are, in fact, highly effective. When possible, it is best not to try to coerce faculty who have a strong face-to-face preference to teach online labs. Because of the substantial design investment in online labs, it is wise to try to plan for faculty to have a longer-term expectation of conducting the lab in the future. Designing a departmentally endorsed online lab set-up for introductory courses cuts down redundant work and can ensure a higher level of consistent quality. It also enhances the delivery of instructors who are teaching the course for the first time as well as adjunct faculty;
- Use collaboration strategies when possible—paired or group—but be sure to structure, support, and monitor collaborative assignments so that better students are not penalized by the "free loader" syndrome. Pairs or groups of students are a powerful method in teaching, providing peer support, opportunities for collaborative learning, instilling cooperative behaviors and so on. However, if the instructor or lab assistant

is not monitoring collaborative groups, one or more may go astray because of an array of interpersonal or situational reasons;

- Technical consistency and excellence: Instructors should, of course, work to minimize technical glitches and promote a culture that reduces technological anxiety through pilot testing of activities, online learning metrics supplied by the learning management system or the software being used, and spot-checking activity progress. A particularly welcomed type of support for students are prerecorded videos that demonstrate lab activities. While these may be the sole demonstration in asynchronous courses (and should be longer and more detailed), they are highly appreciated in synchronous and even face-to-face classes in which they may be more succinct as auxiliary, rather than primary, instructional delivery mechanisms.

7. Conclusions and Limitations

Our study offers a synthesized overview of the current landscape of online lab learning in computing-related disciplines. The results revealed a generally positive reception towards online labs, with both students and faculty acknowledging the progress made post-COVID-19. It also acknowledges the need for instructors and departments of labs to review the modalities on a case-by-case basis. The consensus of responses underscores the importance of continued investment in technological infrastructure to elevate the quality and accessibility of lab learning environments.

Notably, a divergence in perspectives emerged regarding the efficacy of teamwork in online settings, with faculty maintaining a somewhat more favorable view compared to students. Additionally, preferences on lab session modalities indicated a split among students between synchronous and asynchronous formats, while faculty exhibited a preference for synchronous sessions.

A particularly unanimous point among students highlighted the value of recorded demonstrations, suggesting a best practice for faculty to incorporate such resources, regardless of whether synchronous sessions are offered. These recordings not only complement live demonstrations but also serve as a persistent resource for students, enhancing flexibility and self-paced learning.

The issue, then, is not the fact that virtual labs can be successful, but rather when and how they are most successful, including the level to which they are supplemental to face-to-face labs, taking into account technology advances and instructional design innovation.

In conclusion, this study suggested key considerations for the future of lab learning experiences. It emphasizes the need for alignment between student needs and faculty expectations, the adoption of effective collaboration strategies in online formats, and the thoughtful integration of recorded materials to support diverse learning preferences. These insights pave the way for refining online lab courses to better accommodate the continuing evolution of computing education.

Future research can investigate how to implement the findings established by this study. First, research can identify the concrete best practices (and technologies) by discipline. Second, it would be helpful to investigate practices that some faculty have successfully used to reduce faculty effort which has been problematic from their perspective. Third, while students seem to be generally positive about collaboration, it would be helpful to know by discipline what strategies are most effective in structuring the collaborative experience. Finally, while wildly popular, quality recorded demonstrations are quite time consuming to create so it would be helpful to investigate both what types of demonstrations are most useful by discipline, and how such demonstrations can be most efficaciously co-produced.

Some of the limitations of the study include the following considerations. All single-institution samples have limited generalizability until aggregated with other studies. The student N is adequate for such a study, but our faculty N of 20 is small and thus comparisons with the student data need to be cautiously interpreted until corroborated with other studies. The study was based on a pragmatic framework of issues rather than a theory, per se, in order to focus on gathering post-pandemic data. Thus, the study relies on descriptive statistics rather than more robust analytic techniques.

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References

1. Van Wart, M.; Ni, A.; Medina, P.; Canelon, J.; Kordrostami, M.; Zhang, J.; Liu, Y. Integrating Students' Perspectives about Online Learning: A Hierarchy of Factors. *Int. J. Educ. Technol. High. Educ.* **2020**, *17*, 53. [CrossRef]
2. Venkatesh, V.; Morris, M.G.; Davis, G.B.; Davis, F.D. User Acceptance of Information Technology: Toward a Unified View. *MIS Q.* **2003**, *27*, 425–478. [CrossRef]
3. Chan, P.; Van Gerven, T.; Dubois, J.-L.; Bernaerts, K. Virtual Chemical Laboratories: A Systematic Literature Review of Research, Technologies and Instructional Design. *Comput. Educ. Open* **2021**, *2*, 100053. [CrossRef]
4. Panasiuk, O.; Akimova, L.; Kuznietsova, O.; Panasiuk, I. Virtual Laboratories for Engineering Education. In Proceedings of the 2021 11th International Conference on Advanced Computer Information, Deggendorf, Germany, 15–17 September 2021.
5. Bhagyavati, K. Laboratory Exercises in Online Information Assurance Courses. *J. Educ. Resour. Comput.* **2006**, *6*, 4. [CrossRef]
6. Wolf, T. Assessing Student Learning in a Virtual Laboratory Environment. *IEEE Trans. Educ.* **2010**, *53*, 216–222. [CrossRef]
7. Alharbi, A. Re-Imagining Computer Laboratories for Teaching Introductory Programming Concepts Using Web-Based Integrated Development Environments: Opportunities and Challenges. In Proceedings of the 4th World Symposium on Software Engineering, Xiamen, China, 28–30 September 2022; Association for Computing Machinery: New York, NY, USA, 2022; pp. 67–74.
8. Vadlana, B.; Lakshmi Bai, K.J.; Gajavelly, K.; Vineeth, P.; Sameer, M.; Hakeemuddin, S.K. Virtual lab environment for programming using mean stack. In Proceedings of the 2022 4th International Conference on Smart Systems and Inventive Technology (ICSSIT), Tirunelveli, India, 20–22 January 2022; pp. 1227–1230.
9. Rey, W.P.; Defensor, K.E.R. VirtualTechLab (VTL): Innovative pedagogy for integrating virtual labs into e-learning for computer hardware fundamentals. In Proceedings of the 2024 10th International Conference on Frontiers of Educational Technologies, Malacca, Malaysia, 14–16 June 2024; Association for Computing Machinery: New York, NY, USA, 2024; pp. 25–31.
10. Kavitha, D.; Anitha, D.; Manoharan, P.S. Project Based Learning and Proctored Online Assessment in Lab Courses to Enhance CDIO Skills—A Case Study of Microcontroller Laboratory Course. *J. Eng. Educ. Transform.* **2024**, *37*, 98. [CrossRef]
11. Lynch, T.; Ghergulescu, I. Review of virtual labs as the emerging technologies for teaching stem subjects. In Proceedings of the 11th International Technology, Education and Development Conference, Valencia, Spain, 6–8 March 2017.
12. Chelloug, S.; Ashfaq, H.; Alsuhibany, S.; Mohammad, S.; Alsufyani, A.; Jalal, A.; Park, J. Real Objects Understanding Using 3D Haptic Virtual Reality for E-Learning Education. *Comput. Mater. Contin.* **2022**, *74*, 1607–1624. [CrossRef]
13. Diwakar, S.; Kolil, V.K.; Francis, S.P.; Achuthan, K. Intrinsic and Extrinsic Motivation among Students for Laboratory Courses—Assessing the Impact of Virtual Laboratories. *Comput. Educ.* **2023**, *198*, 104758. [CrossRef]
14. Yücel, F.; Sultan Ünal, H.; Surer, E.; Huvaj, N. A Modular Serious Game Development Framework for Virtual Laboratory Courses. *IEEE Trans. Learn. Technol.* **2024**, *17*, 966–981. [CrossRef]
15. Usman, M.; Suyanta, K.H. Virtual Lab as Distance Learning Media to Enhance Student's Science Process Skill during the COVID-19 Pandemic. *J. Phys. Conf. Ser.* **2021**, *1882*, 12126. [CrossRef]
16. Hwang, W.-Y.; Kongcharoen, C.; Ghinea, G. To Enhance Collaborative Learning and Practice Network Knowledge with a Virtualization Laboratory and Online Synchronous Discussion. *Int. Rev. Res. Open Distrib. Learn.* **2014**, *15*, 113–137. [CrossRef]
17. Luse, A.; Shadbad, F.N. Teaching Tip: Hackalytics: Using Computer Hacking to Engage Students in Analytics. *J. Inf. Syst. Educ.* **2023**, *34*, 370–386.
18. Garg, S.; Chowdhary, S.K.; Acharya, B.M. The Overview of the Relevance of Virtual Reality and Its Applications in Education. In Proceedings of the 2022 International Conference on Machine Learning, Computer Systems and Security (MLCSS), Bhubaneswar, India, 5–6 August 2022.

19. Alexander, B.; Hou, Y.; Khan, B.; Jin, J. Learn Programming In Virtual Reality? A Case Study of Computer Science Students. In Proceedings of the 2022 IEEE Global Engineering Education Conference (EDUCON), Tunis, Tunisia, 28–31 March 2022; p. 275.
20. Du, X.; Dai, M.; Tang, H.; Hung, J.-L.; Li, H.; Zheng, J. A Multimodal Analysis of College Students' Collaborative Problem Solving in Virtual Experimentation Activities: A Perspective of Cognitive Load. *J. Comput. High. Educ.* **2022**, *35*, 272–295. [CrossRef]
21. Reginald, G. Teaching and Learning Using Virtual Labs: Investigating the Effects on Students' Self-Regulation. *Cogent Educ.* **2023**, *10*, 2172308. [CrossRef]
22. Van den Beemt, A.; Groothuijsen, S.; Ozkan, L.; Hendrix, W. Remote Labs in Higher Engineering Education: Engaging Students with Active Learning Pedagogy. *J. Comput. High. Educ.* **2023**, *35*, 320–340. [CrossRef] [PubMed]
23. Xia, Y.; Hu, Y.; Wu, C.; Yang, L.; Lei, M. Challenges of Online Learning amid the COVID-19: College Students' Perspective. *Front. Psychol.* **2022**, *13*, 1037311. [CrossRef]
24. Medina, P.; Vij, N.; Ni, A.; Zhang, J.; Hou, Y.; McIntyre, M. The "Mainstreaming" of Online Teaching and Conflicted Faculty Perceptions. *Int. J. Adult Educ. Technol.* **2022**, *13*, 1–16. [CrossRef]
25. Glassey, J.; Magalhães, F.D. Virtual Labs—Love Them or Hate Them, They Are Likely to Be Used More in the Future. *Educ. Chem. Eng.* **2020**, *33*, 76–77. [CrossRef]
26. Wazan, A.S.; Kuhail, M.A.; Hayawi, K.; Venant, R. Which virtualization technology is right for my online it educational labs? In Proceedings of the 2021 IEEE Global Engineering Education Conference (EDUCON), Online, 21–23 April 2021; pp. 1254–1261.
27. Jurc, J.; Kontsek, M.; Sterbak, M. Information Systems of Virtual Laboratories and Their Development. In Proceedings of the 19th International Conference on Emerging eLearning Technologies and Applications (ICETA), Košice, Slovakia, 11–12 November 2021.
28. Wijenayake, C.; D'Souza, M.; Khatamianfar, A.; Bialkowski, K.; Ros, M.; Sutton, P. Managing hands-on electrical and computer engineering labs during the COVID-19 pandemic. In Proceedings of the 2021 IEEE International Conference on Engineering, Technology & Education (TALE), Wuhan, China, 5–8 December 2021; pp. 1051–1056.
29. Tomeo-Reyes, I.; Chen, Z.; Wijenayake, C.; Khatamianfar, A. Investigating Different Approaches on Online Laboratory Practices. In Proceedings of the IEEE International Conference on Teaching, Assessment and Learning for Engineering 2023, Auckland, New Zealand, 27 November–1 December 2023; p. 8.
30. Goryll, M.; Thornton, T.J.; Wang, C.; Phillips, S.M.; Allee, D. Online undergraduate laboratories in electrical engineering. In Proceedings of the 49th IEEE Frontiers in Education Conference, FIE 2019, Cincinnati, OH, USA, 16–19 October 2019. [CrossRef]
31. Wijenayake, C.; Wickremasinghe, K.; Abarajithan, G.; Madanayake, A.; Edussooriya, C.; Samarasinghe, K. A Mostly-Online CAS Teaching Experience. In Proceedings of the 2022 IEEE International Symposium on Circuits and Systems (ISCAS), Austin, TX, USA, 27 May–1 June 2022; pp. 1783–1787.
32. Elkhatat, A.M.; Al-Muhtaseb, S.A. Hybrid Online-Flipped Learning Pedagogy for Teaching Laboratory Courses to Mitigate the Pandemic COVID-19 Confinement and Enable Effective Sustainable Delivery: Investigation of Attaining Course Learning Outcome. *SN Soc. Sci.* **2021**, *1*, 113. [CrossRef]
33. Troya, J.; Parejo, J.A.; Segura, S.; Gámez-Díaz, A.; Márquez-Chamorro, A.E.; del-Río-Ortega, A. Flipping Laboratory Sessions in a Computer Science Course: An Experience Report. *IEEE Trans. Educ.* **2021**, *64*, 139–146. [CrossRef]
34. Ironsi, C.S.; Solomon Ironsi, S. A Switch from Flipped Classroom to Hybrid Educational Model: Perceived Effectiveness of Mode of Instructional Delivery. *Open Learn. J. Open Distance e-Learn.* **2024**, *2024*, 2385346. [CrossRef]
35. Elmoazen, R.; Saqr, M.; Khalil, M.; Wasson, B. Learning Analytics in Virtual Laboratories: A Systematic Literature Review of Empirical Research. *Smart Learn. Environ.* **2023**, *10*, 23. [CrossRef]
36. Servin, C.; Pagel, M.; Webb, E. An authentic peer-led team learning program for community colleges. In Proceedings of the 55th ACM Technical Symposium on Computer Science Education, Toronto, ON, Canada, 15–18 March 2023.
37. Jiang, A.; Simion, B. Help Supports during Online Delivery. In Proceedings of the 53rd ACM Technical Symposium on Computer Science Education, Providence, RI, USA, 2–5 March 2022.
38. Hou, Y.; Ghasemkhani, A.; Aldirawi, H.; McIntyre, M.; Van Wart, M. Shifts in STEM Student Perceptions of Online Classes across 18 Months. *Am. J. Distance Educ.* **2022**, *38*, 220–238. [CrossRef]
39. Hackett, P.; Wermelinger, M.; Kear, K.; Douce, C. Using a virtual computing lab to teach programming at a distance. In Proceedings of the 7th Conference on Computing Education Practice, Durham, UK, 6 January 2023; Association for Computing Machinery: New York, NY, USA, 2023; pp. 5–8.
40. Maheshwari, S.; Jain, P.; Ligon, B.L.; Thammasitboon, S. Twelve Tips for Creating and Supporting a Meaningful Asynchronous Learning as Parts of Virtual Transition of a Curriculum. *MedEdPublish* **2021**, *10*, 111. [CrossRef] [PubMed]
41. Hou, Y.; Muheidat, F.; Usher, T.; Prado, W.; Guo, X.; Wart, M.V. Evaluation of the COVID-19 Shock on STEM Laboratory Courses. In Proceedings of the 2021 IEEE Global Engineering Education Conference (EDUCON), Vienna, Austria, 21–23 April 2021.
42. Worley, W.L.; Tesdell, L.S. Instructor Time and Effort in Online and Face-to-Face Teaching: Lessons Learned. *IEEE Trans. Prof. Commun.* **2009**, *52*, 138–151. [CrossRef]
43. Dumont, G.; Ni, A.Y.; Van Wart, M.; Beck, C.; Pei, H. The Effect of the COVID Pandemic on Faculty Adoption of Online Teaching: Reduced Resistance but Strong Persistent Concerns. *Cogent Educ.* **2021**, *8*, 1976928. [CrossRef]
44. Garrison, D.R.; Anderson, T.; Archer, W. A Theory of Critical Inquiry in Online Distance Education. In *Handbook of Distance Education*; L. Erlbaum Associates: Mahwah, NJ, USA, 2003; Volume 1, pp. 113–127, ISBN 978-1-4106-0729-4.
45. Kehrwald, B. Understanding Social Presence in Text-based Online Learning Environments. *Distance Educ.* **2008**, *29*, 89–106. [CrossRef]

46. Asoodar, M.; Vaezi, S.; Izanloo, B. Framework to Improve E-Learner Satisfaction and Further Strengthen e-Learning Implementation. *Comput. Hum. Behav.* **2016**, *63*, 704–716. [CrossRef]
47. Eom, S.B.; Wen, H.J.; Ashill, N. The Determinants of Students' Perceived Learning Outcomes and Satisfaction in University Online Education: An Empirical Investigation. *Decis. Sci. J. Innov. Educ.* **2006**, *4*, 215–235. [CrossRef]
48. Richardson, J.C.; Maeda, Y.; Lv, J.; Caskurlu, S. Social Presence in Relation to Students' Satisfaction and Learning in the Online Environment: A Meta-Analysis. *Comput. Hum. Behav.* **2017**, *71*, 402–417. [CrossRef]
49. Joo, Y.J.; Lim, K.Y.; Kim, E.K. Online University Students' Satisfaction and Persistence: Examining Perceived Level of Presence, Usefulness and Ease of Use as Predictors in a Structural Model. *Comput. Educ.* **2011**, *57*, 1654–1664. [CrossRef]
50. So, H.-J.; Brush, T.A. Student Perceptions of Collaborative Learning, Social Presence and Satisfaction in a Blended Learning Environment: Relationships and Critical Factors. *Comput. Educ.* **2008**, *51*, 318–336. [CrossRef]
51. Konak, A.; Bartolacci, M.R. Using a Virtual Computing Laboratory to Foster Collaborative Learning for Information Security and Information Technology Education. *J. Cybersecur. Educ. Res. Pract.* **2016**, *2016*, 2. [CrossRef]
52. Muilenburg, L.Y.; Berge, Z.L. Student Barriers to Online Learning: A Factor Analytic Study. *Distance Educ.* **2005**, *26*, 29–48. [CrossRef]
53. Mishra, L.; Gupta, T.; Shree, A. Online Teaching-Learning in Higher Education during Lockdown Period of COVID-19 Pandemic. *Int. J. Educ. Res. Open* **2020**, *1*, 100012. [CrossRef]
54. Aldwairi, M. Evaluating Virtual Laboratory Platforms for Supporting On-Line Information Security Courses. *Glob. J. Eng. Educ.* **2022**, *24*, 1–6.
55. Wagner, K.G.; Myers, M.C.; Konak, A. Fostering student learning in information security fields through collaborative learning in virtual computer laboratories. In Proceedings of the 2013 IEEE Integrated STEM Education Conference (ISEC), Princeton, NJ, USA, 9 March 2013; pp. 1–4.
56. Coffey, L. *Students Distancing from Distance Learning*; Inside Higher Ed: Washington, DC, USA, 2024.
57. Carlton, G. Online Learning Statistics, Forbes (Forbes Advisor). 23 August 2024. Available online: https://www.forbes.com/advisor/education/online-colleges/online-learning-stats/ (accessed on 8 December 2024).
58. Hassan, M. Online Teaching Challenges during COVID-19 Pandemic. *Int. J. Inf. Educ. Technol.* **2021**, *11*, 41–46. [CrossRef]