Student Experiences of Hybrid and Online Engineering Labs in a Logic Control Course

Computer Applications in Engineering Education

WILEY

RESEARCH ARTICLE OPEN ACCESS

Student Experiences of Hybrid and Online Engineering Labs in a Logic Control Course

Yihua Zhang[1] | Christian Stöhr[1] | Susanne Strömberg Jämsvi[2] | Jens Kabo[1] | Johan Malmqvist[3]

[1]Department of Communication and Learning in Science, Chalmers University of Technology, Gothenburg, Sweden | [2]Department of Educational Work, University of Borås, Borås, Sweden | [3]Department of Industrial and Materials Science, Chalmers University of Technology, Gothenburg, Sweden

Correspondence: Yihua Zhang (yihua@chalmers.se)

Received: 7 October 2024 | **Revised:** 6 February 2025 | **Accepted:** 24 March 2025

Funding: The work was funded by the European Union Erasmus+ program, grant number 2020-1- DE01-KA226-HE-005760.

Keywords: Community of Inquiry | engineering education | hybrid learning | lab training | online learning

ABSTRACT

In the rapidly evolving landscape of engineering education, the shift toward online and hybrid lab formats requires a critical examination of their impact on students' learning experiences. This study investigates the experiences of 82 students in a logic control course with campus, remote, and simulation labs, through the lens of the Community of Inquiry framework. Although our qualitative thematic analysis confirms students' general preference for campus labs, we extend this observation through nuanced insights into the cognitive, teaching, and social elements of students' perceptions of their learning experiences in the different lab formats. Students appreciate the increased accessibility and flexibility of remote options, while also identifying challenges and limitations for cognitive engagement, instructional support, and social connection. Our results suggest that with targeted improvements, online and hybrid labs can enhance students' learning experience considerably, particularly if integrated purposefully with campus labs. We discuss theoretical and practical key implications for designing blended lab environments.

1 | Introduction

In contemporary engineering education, labs are central learning activities that offer opportunities for students to connect theories and concepts with observations of phenomena [1]. Labs have important merits for practical skills training such as the opportunity to handle real equipment and collaborate with teachers and students on site. However, campus labs typically are expensive, have time and access restrictions and raise safety concerns [2]. Fueled by technological advancements, educators therefore have experimented with different forms of online labs as potentially valid supplements or alternatives [3]. Online labs hold particular promise in addressing these challenges, as they can provide more flexible access, reduce costs, enable safe experimentation, and allow for scalability [2, 4, 5], supporting diverse learning needs and fostering innovative approaches to engineering education.

Although this has attracted a substantial amount of scholarly work, more recent studies have identified considerable gaps and shortcomings in our understanding of online labs as educational activities. Post et al. [4] critically observe in their review that scholars have predominantly focused on presenting the technical details of online lab setups and that examinations of educational benefits and drawbacks have been superficial. Studies evaluating online lab formats have also been criticized for their predominant focus on cognitive learning outcomes [6] and content knowledge lacking diversity in theoretical and methodological approaches [7]. Even though focusing on academic achievement and other valued learning outcomes has a longstanding tradition in science education evaluation and research, it alone cannot provide a comprehensive understanding of the educational process [8]. May et al. [9] conclude that much of the online lab research so far has only reinforced the point that technology does not directly affect learning. Thus, there is an ongoing need to study online labs from different theoretical and empirical perspectives, including combinations of different lab modalities [6] as well as "individual experiences, the role of personal characteristics or environments that afforded social learning, including interactions with faculty or teaching assistants" [7].

This paper builds on Fraser's notion that students have a large stake in what happens to them, and their reactions to and perceptions of their learning experiences are significant and important parameters of the social and psychological dimensions of learning environments [8]. We attempt to contribute to the scholarly discourse about online labs by examining student perceptions in a project- and team-based lab course in logic control at a Swedish technical university. In this course, students conduct campus labs as well as simulations and remote labs, that is, online labs, in project pairs, with and without the teacher's presence. This empirical setup provides us with the opportunity to study student perspectives of different lab formats within the same course.

To address the multi-dimensionality of student perceptions, we use the Community of Inquiry (CoI) [10] as a conceptual framework providing the theoretical and analytical basis for this study. The CoI framework revolves around forming an educational CoI, comprising students and teachers with a shared objective, engaging in an inquiry process to develop and enrich knowledge using deep, meaningful, individual, and collaborative methods [11]. When learners are engaged in (and can create) an interactive and inquiry-based online learning environment, the CoI framework offers a valid way of understanding learners' experiences of the learning process. The CoI framework offers a comprehensive exploration in capturing the learning experiences from three different dimensions (cognitive, social, and teaching), which are all relevant to creating high-quality educational experiences. By analyzing students' reflective writings after the course, we aim to provide more nuanced insights into the cognitive, teaching, and social elements of students' learning experiences in hybrid and online lab training. The research question, examined in light of the three elements within the CoI framework, is as follows:

How do engineering students perceive the cognitive, teaching, and social elements of their learning experiences in a logic control course with a combination of campus labs, remote labs, and simulations?

Before presenting our methodology and results, we continue with a broad review of prior research on online labs, followed by a more detailed introduction of the CoI framework.

2 | Prior Research

Previous research on lab sessions in engineering education has employed a wide range of terminologies to describe different lab formats. These terms include physical labs [4], traditional labs [12], hands-on labs [13, 14], real labs [2], remotely operated labs [13], simulated labs [13, 14], and virtual labs [2]. To address this terminological ambiguity, this study adopts standardized vocabulary for the different types of lab formats. With "campus lab," we refer to traditional lab facilities where students participate on campus. "Online lab" is used as an umbrella term, where the literature generally distinguishes two types: remote labs and simulations [15]. "Remote lab" is used to represent real-life experimental setups controlled remotely via the internet—either directly or via instructions to staff on site. "Simulations" are software-based lab environments replicating real experiments. Finally, the term "hybrid lab" has typically been employed in literature to refer to setups with different lab formats in terms of their nature, like remote labs and simulations [16, 17], or campus labs and simulations [18]. However, in this study, the setup involves diverse lab formats not only in nature, but also in location, such as campus or online. Therefore, to avoid confusion, we use "hybrid" to denote a mix of lab formats across locations, that is, campus and online labs, and we use "blended" instead to describe a mix of lab formats differing in nature, such as simulations, campus labs or remote labs.

Several studies have identified potential benefits of remote labs and simulations. Foremost, as low-cost alternatives to campus labs, they are flexible as they can be accessed whenever or wherever by students [2, 4]. Increased efficiency via remote labs can be achieved through nonstop scheduling throughout the day, less or no setup time of equipment, or distance support from teachers, enabling them to simultaneously supervise several groups of students [4]. Furthermore, the benefits of simulations include simplified maintenance [19], resistance to damage, easy creation of multi-component experiments, and possibility to modify parameters that are hard to change in a real system [5]. Thus, students can repeat experiments at their own pace, mistakes are easily fixed, and results are guaranteed [20]. Additionally, several students can use the same virtual equipment at the same time [5]. Remote labs and simulations, despite distance, encourage peer interaction as they make remote collaboration among students possible [2].

Scholars have also pointed out some of the drawbacks of online labs. Simulations have been criticized because of their lack of real-life feeling and that they seldom create awareness about health and safety issues [19]. Due to the virtual nature of the learning environment, students can be less serious, responsible, and careful when learning in simulations [5]. There also exists a risk of oversimplifications [19]. Data generated in simulations often lacks variation, which may result in students not gaining experience of analyzing or interpreting incorrect or uncharacteristic data [21]. Similarly, critiques of remote labs argue that most remote labs hardly offer a realistic lab environment, apart from having access to real measurement data, students have the same feeling as performing a simulation [2]. Though online labs are unlikely to replace campus labs completely, the online learning experience can be improved through more careful design and coordination of group and individual activities [13]. Teacher support is essential to facilitate students' learning experiences in online labs, however, organizing lab activities within remote instructional contexts can be challenging for the teacher [22].

The complementary combination of various lab formats requires further exploration, given that different lab types possess distinct strengths and weaknesses [9]. Among the few studies in this area, [18] and [17] have both found promising results in terms of skill development and student learning experience when combining simulations with campus or remote labs.

Finally, the social dimension of learning in engineering lab environments is under-researched and requires more in-depth investigations [6]. Student collaboration is generally considered crucial in modern engineering education [23] and of particular relevance in online learning [24]. Scholars have since long called for integrating teamwork and peer interaction as essential components of online lab settings [14], and studies confirm the value of collaborative learning, for example, in remote labs [25, 26]. Explore the integration of desktop-sharing technologies to support online lab collaboration.

In sum, while research on online labs has identified several benefits and drawbacks, gaps remain, particularly regarding the combination of different lab formats and the social dimension of learning.

3 | The CoI Framework

The CoI framework is rooted in a social constructivist view of learning through a sense-making process of learners' interactions in a social-cultural context [27]. Drawing upon Dewey's general scientific reasoning process [28] and the concept of a CoI initially proposed by [29] and further developed within an educational context by [30], this framework is a "generic and coherent structure of a transactional educational experience whose core function is to manage and monitor the dynamic for thinking and learning collaboratively" [31]. Specifically, CoI proposes conditions that structure the process of learning, with significant applications in online environments. In its original form, the conditions were conceptualized around three interdependent elements: (1) cognitive presence which outlines the process of learning and is "the core thinking and meaning-making element when participants are engaged in individual and cooperative practical inquiry" [11]; (2) social presence which reflects the human experience of learning and is the degree to which students and teachers "feel socially and emotionally connected with others in an online environment" [32]; and (3) teaching presence which is the guidance required to promote learning and "involves preparing, planning, and structuring learning activities—monitoring, supporting, and guiding students' inquiry and directing and leading learning processes" [11] (see Figure 1). The term "presence" reflects the connectedness required to form a community [11]. Besides online learning environments, the CoI framework has also been established for hybrid learning environments [33].

Since the introduction of the CoI framework, it has gained considerable attention as a theoretical and methodological means to understand and facilitate learning experiences in online learning environments [34] and has been widely used in online education research. It is argued to account for much of the complexity of the teaching and learning transaction [35], appeal to common sense, and practitioners who hope to rationalize their teaching experiences and provide guidance for online learning research [36]. However, its application in engineering education is quite new [37]. The majority of studies using the CoI framework are conducted within social science education [38], which is potentially due to its particular usefulness in disciplines that lack a dominant educational paradigm [39, 40]. In [41], the investigation of CoI presence in sciences and humanities disciplines revealed notable differences. Cognitive presence was more evident in science disciplines, while social presence was more pronounced in humanities disciplines.

Numerous researchers have also explored the connection between CoI presences and students' perceptions of their learning experiences. For instance, previous studies have recognized the three presences as crucial factors influencing students' satisfaction [42–49]. The role of social presence for learning is a particular focus area in CoI research given that this aspect is often overlooked in online learning environments [50] and is not known to be the focus in science disciplines [41]. Some studies suggest that it is the most important factor in online education [51–54]. However, CoI has been criticized for overemphasizing social presence [55], and substantial research found that cognitive and teaching presence hold greater importance compared to social presence [56–59]. Thus, studies have offered mixed conclusions regarding the importance of social presence [37]. Together, these findings reinforce the necessity for further research to understand students' experiences of the three different presences in online environments.

For the current study, we selected the CoI framework because it provides a holistic lens for examining learning experiences in

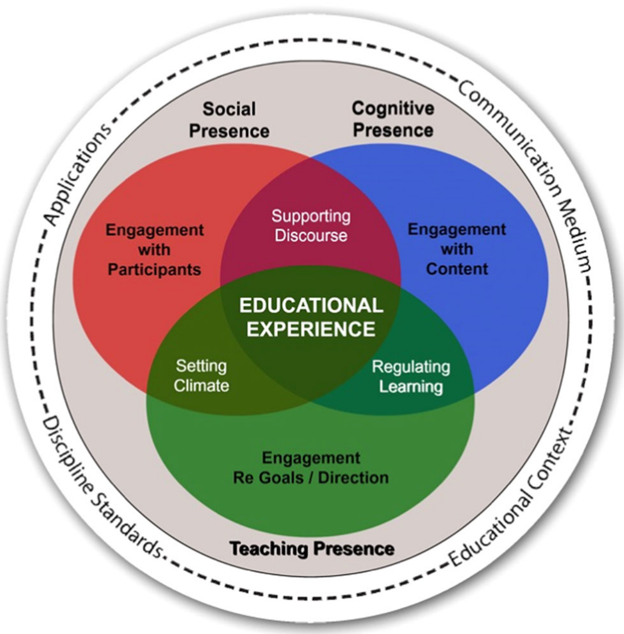

FIGURE 1 | The Community of Inquiry framework. Image used with permission from the Community of Inquiry website and licensed under the CC-BY-SA International 4.0 license (https://creativecommons.org/licenses/by-sa/4.0/). The original image is located at https://www.thecommunityofinquiry.org/framework.

contexts where physical and virtual components merge—such as our combination of campus labs, remote labs, and simulations. The students (or the student pairs) and the teacher in the course constitute a CoI as they share common learning objectives and participate in an inquiry process, employing collaborative approaches, making the application of the framework a promising approach. Although other models exist for analyzing online learning, CoI's explicit attention to social and teaching dimensions—alongside the cognitive aspects—makes it particularly suited for investigating the blended lab context, where student engagement and teacher facilitation are expected to play critical roles in successful outcomes.

4 | Methods

4.1 | Research Approach

To examine students' perceptions of their learning experiences in relation to the different lab formats, we conducted a qualitative study, applying CoI as a conceptual framework for question design and analysis. Through a qualitative approach, we aimed to capture rich narratives within their contextual setting [60].

We designed prompts to guide students' short reflective writings that were voluntarily done at the end of the course. The prompts were based on the three presences of the CoI framework to elicit insights into students' learning experiences. Despite this conceptual anchor, the prompts were formulated openly and consisted mainly of "How" questions (see Appendix A). This approach aimed to collect students' reflections in their own words to gain rich descriptions and variation in the responses. We analyzed the students' written reflections using thematic analysis [61] for "identifying, analyzing and reporting patterns (themes) within data".

4.2 | Research Context

This study examines a project-based course in logic control at Chalmers University of Technology. The course is given at the end of the first year of the BSc programs in Electrical Engineering and Mechatronics Engineering. When the study was conducted, a total of 94 students were enrolled in the course. The course has a collaborative setup, where students are paired to work on one of three project tasks of similar complexity that focus on training programming of microcontrollers and PLCs (programmable logic controllers), and the use of electronic components for communication between the two control systems. The projects are built on students' first-year studies such as computer engineering, electric circuits, and C programming. The course supplements this foundation with new content via seven 2-h lectures early in the course and course literature in form of two compendia, various manuals, and datasheets.

Students are scheduled for a total of 24 h in the lab for project work, with attendance mandatory until project completion. Up to 8 h of mandatory lab time can be attended remotely. Simulation models (Codesys for the PLC part, and Tinkercad for the Arduino Uno microcontroller and electrical components) are provided for home preparation as well as 20 h of online sessions for questions between the scheduled lab times. For the lab sessions, student pairs chose to participate in one of three formats: (1) both students attend labs on campus, (2) one student is on campus while the other participates remotely, and (3) both students attend remotely with the teacher handling the equipment. In format (2), although one student is on campus and the other participates at a distance, the remote student actively collaborates with the on-campus student by providing instructions and guidance. This allows both students to engage in problem-solving and work together. In format (3), the teacher follows the instructions given by the remotely participating students, ensuring their active engagement. These interactions enable remote students to maintain a degree of control and collaboration rather than being mere observers. Figure 2 exemplifies the setup for one student attending remotely, featuring one webcam (highlighted in yellow) and one conference microphone (highlighted in red). Communication between students occurred via Zoom, allowing the on-campus student to share their screen and grant control to their remote partner. The conference microphone facilitated simultaneous interaction with the teacher. Figure 3 demonstrates the setup for both students attending remotely, utilizing one webcam (highlighted in yellow) capable of angling to display the breadboard (highlighted in blue). Through Zoom, the teacher shares their

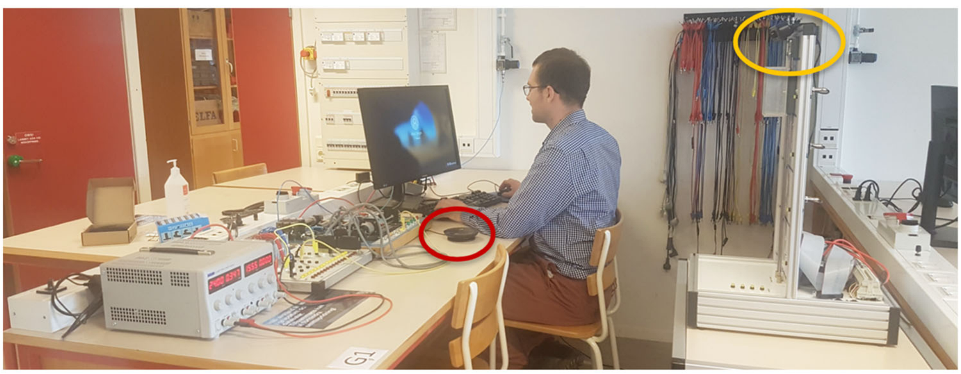

FIGURE 2 | Lab setup featuring one student present on campus and another participating remotely [62]. The setup includes a webcam (highlighted in yellow) and a conference microphone (highlighted in red). Communication occurs via Zoom, allowing the on-campus student to share their screen and grant control to their remote partner, while the conference microphone enables real-time interaction with the teacher.

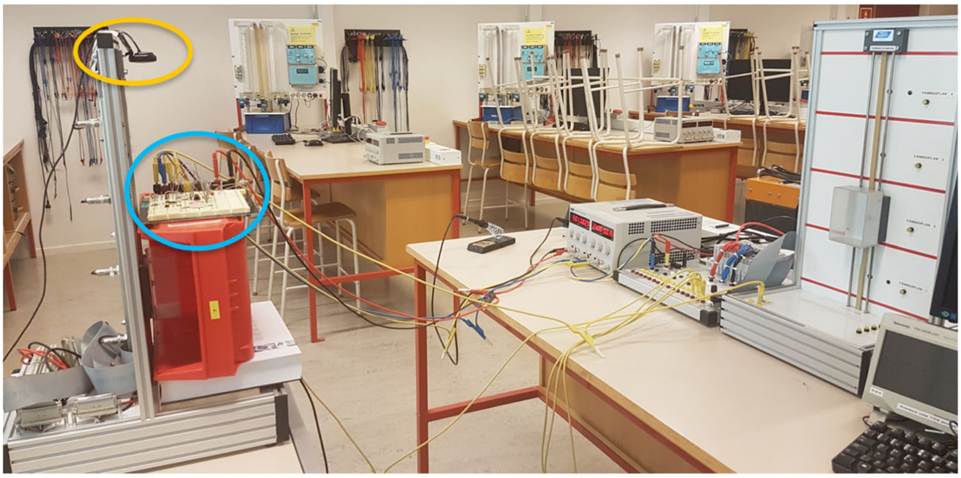

FIGURE 3 | Lab setup featuring both students participating remotely [62]. The setup includes a webcam (highlighted in yellow) angled to display the breadboard (highlighted in blue). Through Zoom, the teacher shares their screen, demonstrates code downloads to the PLC and microcontroller, and conducts functional tests based on the students' instructions.

screen, demonstrates code downloads to the PLC and microcontroller, and conducts functional tests based on the students' instructions. The course assessment consists of four parts: a collaborative project task solved in pairs, a joint written report, an individual short written test, and a paired oral presentation of the project.

4.3 | Data Collection

The core of the writing reflection consisted of three parts: (1) a prompt about the perception of the online learning experiences with remote labs, (2) a prompt about the perception of the online learning experiences with simulations, and (3) a prompt about the perception of online labs in general (see Appendix A for details). The first two prompts asked students to consider CoI-related aspects such as the extent to which the remote setup enhanced or hindered their learning, the collaboration with their peers, and their perception of the teacher support.

The reflection sheet with the prompts was distributed to all 94 students in the course in May 2022. Of those, 82 students submitted their written reflections; we do not have information about the reasons for nonparticipation. This results in a response rate of 87%, which is comparatively high for voluntary self-reports. The reflections were written in either English or Swedish, and before the analysis, the authors translated all Swedish reflections into English. If any ambiguity arose while reading a translated quote, we double-checked it against the original Swedish version.

4.4 | Data Analysis

The students' written reflections were analyzed using thematic analysis, focusing on iterative and thoughtful engagement with both the data and the coding process. It is important to note that although not all students participated in remote labs, they were all impacted by the hybrid setup of the course. Therefore, we included the reflections from all students to understand how the hybrid labs setup influenced their learning experiences. Two of the authors took the lead in the initial coding process, systematically reading and coding the data. To ensure a rigorous and collaborative approach, all authors participated in multiple rounds of back-and-forth discussions to refine and reflect on the codes and review themes. This iterative and collaborative approach helped strengthen the analytic process and aimed to enhance trustworthiness by triangulating perspectives.

As the prompts were based on CoI as a conceptual framework, the analysis was done along three strands corresponding to the CoI presences, namely, students' perceptions of: (1) conducting remote labs and simulations, (2) the support provided by teachers, and (3) the collaborative setup. We relate the first strand to cognitive presence, as it captures students' reflections on how the setup facilitated or hindered their learning processes and engagement with the course content. The second strand directly maps onto teaching presence, reflecting students' experiences of teacher guidance and facilitation. The third strand aligns with social presence, focusing on students' interactions and collaboration with peers.

For the thematic analysis within each strand, we adhered to the six phases of thematic analysis outlined by [61, 63]: (1) familiarizing oneself with the data set, (2) coding, (3) generating initial themes, (4) developing and reviewing themes, (5) refining, defining and naming themes, and (6) writing up. To illustrate our approach, we provide an example of our analytical process based on this example quote from the student reflections:

> *I find it difficult to have a functioning collaboration with my lab partner. The one attending in person gets a heavier load.*

We began by reading the text multiple times to familiarize ourselves with it. Next, we assigned code labels to the data and generated initial themes, such as "imbalanced workload distribution." When all student writings were coded, we had a list of the different themes identified across the student writings. After several iterative rounds of refinement and recoding, we then began to consider how these various themes could be grouped into overarching CoI dimensions relevant to our research question. In the example provided, we categorized the generated theme under the collaborative setup dimension. Then, we moved to the next phase, where we assessed whether there was sufficient cohesion within the data to support each theme and whether the identified themes captured the most important aspects of the data in relation to the research question. Following this, the themes were refined where necessary. Finally, we proceeded to the last step, where we composed the article, providing quotations to support the credibility of our findings [64].

5 | Results

In the thematic analysis along three strands corresponding to the CoI presences, we examine students' perceptions of their learning experiences of using remote labs and simulations and their general attitudes to online labs. To present a clear overview, we organized the results into five tables. Four of them (Tables 1, 2, 4, and 5) address the students' reflections on cognitive and social presence in remote labs and simulations. Table 3 presents students' perspectives on teaching presence, as the student reflections in this dimension addressed mostly the whole course. Each table includes our explanations of the themes alongside example quotes. After each table, we provide a brief recap of the results, summarizing and reflecting on the key insights captured in the table.

5.1 | Cognitive Presence: Conducting Remote Labs and Simulations

Students widely appreciated the remote lab option for its ease of access and flexibility, particularly in situations where illness or limited campus access might otherwise impede their progress (see Table 1). They emphasized that the ability to continue working off-campus maintained their engagement with the course material despite external constraints. At the same time, many students stressed that remote labs served best as a complement rather than a full replacement for hands-on experiences in campus labs. Although remote setups offered convenience, the tactile and visual dimensions of physically handling equipment were still viewed as fundamental to deeper understanding.

However, the remote environment also introduced drawbacks. A notable physical disconnect arose from being unable to see or handle the equipment directly, which some students found to be a significant barrier to interpreting real-world signals and nuances. This challenge was compounded by visual difficulties, hindering precise observation of on-site processes. Furthermore, technical difficulties—including system malfunctions and connectivity interruptions—occasionally disrupted students' learning flow.

Students generally found simulations to be an effective tool for deepening their understanding of the course material (see Table 2). They appreciated the risk-free environment, where repeated, low-consequence experimentation enabled them to

TABLE 1 | Cognitive presence in remote labs: themes, theme explanations, and example quotes.

CoI dimensions	Themes	Theme explanations	Example quotes
Conducting online labs (cognitive presence)	Ease of access, continued learning, flexibility	Students' positive perceptions of remote labs were often attributed to the ease of access. The remote labs enabled students to continue their studies even when they were unwell or could not physically access campus facilities.	*I think it has worked very well with a mix of distance and home lab. It gives greater freedom how the work should be set up in terms of time. It is also positive to be able to participate if you experience symptoms of illness but are not so ill.*
	A complement to campus labs	Students regarded remote labs as a complement rather than a replacement for on-campus labs.	*Remote labs are a good jumping off point for studies in-person labs. They can never replace the in-person labs.*
	Physical disconnect	The lack of direct physical access to the lab was perceived as an obstacle by participants, with some expressing a tangible sense of disconnect in the remote environment.	*They [remote labs] were difficult as you could not look at the physical guys.*
	Visual difficulties	Students reported challenges associated with the suboptimal visual experiences which hindered students' ability to observe and comprehend the activities taking place remotely.	*[It was] a little hard to see what was happening.*
	Technical difficulties	Technical difficulties emerged as a salient concern, disrupting students' learning experience.	*Online labs were more difficult due to technical diff[iculties]. It hinders my learning when interrupted due to system malf[unction].*

TABLE 2 | Cognitive presence in simulations: themes, theme explanations, and example quotes.

CoI dimensions	Themes	Theme explanations	Example quotes
Conducting online labs (cognitive presence)	Providing clarity in understanding	Simulations were perceived as effective in enhancing their learning experiences by most students. They were considered useful in providing additional opportunities to achieve a comprehensive understanding of the course material.	*The simulation has helped to get a true picture of what it is we are doing.*
	Tools for extended practice	The possibility of easy and repeatable testing was considered helpful to achieve higher level learning outcomes.	*The simulator helped a lot to understand the program as you have more time to test.*
	Preparatory function	Students viewed simulations as a valuable preparation for labs and campus sessions, complementing on-site work.	*[Simulations are] a great way to prepare before attending class.*
	A complement to campus labs, continued learning, flexibility	Simulations were seen as a good complement to campus labs, enabling students to continue learning beyond scheduled lab hours and physical access constraints, especially when on-site access was restricted or unavailable. However, students also acknowledged the irreplaceable value of hands-on experience with physical equipment.	*In combination with physical components, I think the simulations do a really great job and are a good way for students to keep practicing outside of the lab, especially when the lab halls aren't open very often.* *Easier to work whenever you want. But sometimes you really needed the real stuff to be able to work.*
	Risk-free experimentation	Students emphasized the advantage of simulations in preventing damage to program or hardware while trying out ideas, thereby establishing simulations as a low-risk, low-consequence environment.	*Working with the simulator allowed us to test ideas without ruining our program or hardware.*
	Initial challenges with unfamiliarity in the setup	Students reported difficulties, in particular in the beginning due to unfamiliarity with simulations.	*It was a little different at first when you did not see everything in front of you and needed to look for functions. Became easier with time.*
	Need for sufficient prior knowledge	Students encountered challenges due to a lack of prior knowledge when utilizing simulations.	*I found it [simulations] quite difficult as I have missed a lot in previous courses that would be useful here.*
	Difficulty bridging simulations and campus labs	Students experienced difficulty of connecting the learning through simulations to actual labs.	*[It was] harder to understand what's going on and if it would work in the real world.*
	Time efficiency	Simulations running faster than real equipment was seen as both an advantage and a drawback. On one hand, simulations were time efficient.	*The simulator usually runs faster than the actuator in the hall, which makes it more efficient when you have to do all the tests and run through a gentleman's lot of programs.*
	Inaccurate speed representation	On the other hand, the speed of simulations was seen as a problem, as it was not always accurate enough to provide a realistic representation of the processes being studied.	*My only problem with the simulator was that the speeds differed from that in the lab.*

TABLE 3 | Teaching presence in the course: themes, theme explanations, and example quotes.

CoI dimensions	Themes	Theme explanations	Example quotes
Teacher support (teaching presence)	Availability of support beyond class	The accessibility of course materials and the availability of supportive teachers were specifically appreciated by students, and teachers were perceived as proactive in providing support, even outside of the regular classroom environment.	*The help from teachers has always been available via email or consultation sessions.*
	Insufficient teacher support	There were also students who exhibited negative reactions toward the level of support provided by teachers.	*Teachers' support was minimal.*
	Difficulty in balancing on-campus and remote support	Students observed that teachers faced difficulties in managing the needs of both on-campus and remote students, often prioritizing the former.	*The teachers were supportive but since they had other groups to help, it takes priority over online.*
	Inferior remote support	It was noted that teacher support in an online learning environment cannot match real-life meetings on campus.	*Support from teachers is sufficient but not comparable to real-life discussion on site.*
	Stress from indirect teacher support	The pedagogical approach of the teachers was also highlighted. Students observed that, instead of providing direct answers, teachers often adopted a rather open approach to feedback provision. This approach was criticized both in terms of tone and content, particularly in the context of an effort-intensive course.	*The teachers are good, but sometimes I think they are a bit harsh. Instead of helping/putting one in the right direction, they let one rather figure out that/problem all by themselves, which can sometimes be very difficult and therefore takes too long and then everything becomes stressful.*

refine their skills without concern for damaging hardware or programs. In addition, simulations were prized for their flexibility and preparatory function, offering opportunities to practice outside scheduled lab hours and arrive at campus sessions better prepared. Some students also highlighted time efficiency, noting that simulations often ran faster than physical equipment, allowing them to iterate solutions more quickly.

Despite these advantages, students faced several learning thresholds. One issue was unfamiliarity with simulation platforms, especially for those lacking prior knowledge or experience, which initially made navigation and troubleshooting difficult. Another challenge involved bridging the gap between simulations and real-world applications. Translating performance in a virtual environment to actual lab outcomes could be unclear, particularly if the speed discrepancies in simulations led to unrealistic representations of physical processes. Consequently, some students questioned whether a successfully tested solution would truly work in practice.

5.2 | Teaching Presence: The Support Provided by Teachers

In contrast to cognitive and social presences—which were closely tied to specific lab formats—student perceptions of teaching presence were often linked to the broader course structure (see Table 3). Overall, students expressed mixed and sometimes opposing views regarding the level and type of teacher support they received. On one hand, many appreciated the accessibility of course materials and found that teachers were proactive in offering help via email or consultation sessions. On the other hand, some students considered the support insufficient, noting that it did not meet their needs in terms of frequency or clarity of guidance.

Teacher support also appeared imbalanced in the hybrid setting, as on-campus students sometimes received more immediate attention than their remote peers. Several students remarked that online guidance could not fully replicate the benefits of real-life discussions on site. Furthermore, the open-ended, less directive pedagogical approach—intended to foster independence—was perceived as stressful by some participants in an effort-intensive course. These students felt they needed more direct cues or reassurance from teachers and found the less guided style contributed to anxiety rather than deeper learning.

5.3 | Social Presence: The Collaborative Setup

From a social presence perspective, most students reported positive collaborative experiences when working remotely (see Table 4). They took responsibility for coordinating their pair work by using communication tools, enabling joint problem-solving and flexible collaboration regardless of location. Through this setup, students engaged actively in each other's learning, supporting one another with challenging tasks and exchanging feedback in real time.

TABLE 4 | Social presence in remote labs: themes, theme explanations, and example quotes.

CoI dimensions	Themes	Theme explanations	Example quotes
The collaborative setup (social presence)	Collaborative problem-solving	Students managed to find ways to communicate with each other before lab sessions and collaborate during labs using various communication tools like Zoom and SMS. The collaboration between students was generally described as "good".	*[We] did everything together and helped [each other] with what was difficult.*
	Imbalanced workload distribution	While there were students who managed to split work evenly in the remote setup, there were others who struggled with the distribution of work, which could lead to a heavier workload for those who were attending in person.	*I find it difficult to have a functioning collaboration with my lab partner. The one attending in person gets a heavier load.*
	Physical disconnect	The distance between remote and on-campus learners was perceived as a challenge to overcome.	*It is always a little bit harder to communicate but it did not hinder us.*

However, not all students found remote collaboration seamless. A number of participants noted imbalanced workload distribution, typically affecting groups in which one partner was on campus while the other participated remotely. In these instances, the on-campus partner often carried a heavier share of the practical tasks, leading to some frustration and a sense of inequity. Additionally, the physical disconnect inherent in remote settings introduced difficulties in reading nonverbal cues and ensuring both partners maintained a shared understanding of the work. Though this distance did not entirely prevent collaboration, it demanded more deliberate efforts to communicate effectively and stay aligned in the lab activities.

Students found simulations generally conducive to collaborative learning, noting that they could distribute tasks efficiently and prepare jointly for assignments (see Table 5). Just as for remote labs, digital platforms such as Zoom and Discord allowed them to work flexibly, regardless of location, and many reported an equitable division of labor, ensuring both partners fully participated and understood the content. At the same time, some students encountered issues with synchronizing learning paces, particularly when partners brought different levels of familiarity or comfort with simulations. Similar to remote labs, the physical disconnect made it challenging to gauge a partner's comprehension without the benefit of face-to-face cues.

In sum, our analysis of students' learning experiences using remote labs and simulations provided a rich and varied number of perspectives highlighting both potentials and challenges. In the following, we discuss the results through the lens of the CoI framework, focusing on cognitive, teaching, and social factors.

6 | Discussion

This study was set out to examine how engineering students' experience the combination of campus labs, remote labs, and simulations in a logic control course. Based on the results presented above, we now discuss these findings through the lens of the CoI framework and consider implications for practice and future research.

6.1 | Cognitive Presence in Online Labs

First, we discuss how the different lab formats facilitate or hinder the students' ability to engage with the content, reflect on their learning, and apply their knowledge. While all three formats typically adhere to project- or problem-based learning with a strong emphasis on cognitive elements [4, 65], our results showed a clear student preference for campus labs, both through the reflections and the comparatively low number of students opting to conduct the labs remotely. This result links the students' preferences with actual experience of a better flow of information and deeper engagement in hands-on experiences, a finding also evidenced by earlier research [4, 66].

Remote labs were seen as a viable alternative when physical attendance was not possible. The main contribution of remote labs to cognitive presence therefore is the support of sustained reflection and continued engagement through increased accessibility and flexibility [2]. However, online elements in courses are generally prone to technical difficulties, and the impeding effect on student learning can be significant [67]. In this particular context, we saw how technical issues such as equipment malfunctions and suboptimal visual experiences hindered students' ability to fully engage and understand the material, thereby negatively impacting cognitive presence. Hence, it is essential that technical issues are resolved not to obstruct the engagement with content. This includes the necessity for excellent camera positioning and resolution for a great visual experience, which can be a particular strength of this lab format [68].

Simulations were recognized for their accessibility, allowing students to work at their own pace and location, and for

TABLE 5 | Social presence in simulations: themes, theme explanations, and example quotes.

CoI dimensions	Themes	Theme explanations	Example quotes
The collaborative setup (social presence)	Balanced workload distribution, collaborative learning	Collaboration in simulations was described as both rewarding and challenging. Students could help each other, distribute work, and prepare jointly for tasks through common communication tools such as Zoom and Discord. As with remote labs, there were students that engaged in true collaborative learning.	*Distribution of work has worked well, and we always make sure that both understand everything.*
	Continued learning, flexibility, collaborative learning	Students stressed again the increased flexibility, which allowed for communication and collaboration at any time and from any location.	*The simulators were good. It helped to be able to work from home with the project. Me and my partner worked together at home and in school.*
	Difficulty in synchronizing learning pace	Coordinating with other students in simulations could be challenging, particularly when there were differences in learning preferences or paces.	*The only problem we had was working at a different pace.*
	Physical disconnect	Compared to campus in-person learning environments where face-to-face interactions and possible nonverbal cues facilitated a better understanding among peers, it was more difficult to assess whether a student had fully comprehended a concept or solution in simulations. This could potentially create obstacles to effective collaboration and learning.	*Due to the distance, it was harder to know if we both understood the solution.*

promoting a deeper understanding of course materials [66]. They offer a resilient learning environment that fosters hypothesis formulation and testing [69]. These factors are key components of enhanced cognitive presence. However, some students found it difficult to translate simulated scenarios to real-life settings, potentially due to oversimplification or limited data variation [19, 21]. These findings align with the literature and underscore the need for well-designed simulations that accurately reflect real lab complexities.

Our findings also highlighted difficulties for learners lacking prior knowledge and familiarity with simulation environments [70]. These results point at the importance of enhancing students' cognitive presence through adequate support to start navigating and understanding the aim of the simulated experience. However, difficult cognitive challenges in the early stages of a project are not necessarily bad for student learning [71] and might help develop the self-regulated learning skills necessary to engage effectively in online learning overall [72].

6.2 | Teaching Presence in Online Labs

Next, we turn our focus to the perceptions regarding instructional design and organization, support, and direct instruction. Students reported that the level of support provided by their teachers was crucial to the success of their online learning experience, underscoring the importance of teaching presence [10]. Our study found that the combination of lab formats resulted in a flexible instructional design, allowing diverse learning paths based on individual needs. This flexibility is a key aspect of teaching presence, as it helps cater to individual preferences and circumstances [73].

Teaching presence also involves facilitating reflective and sustained communication among students. In the context of our study, the paired learning setups were instrumental in promoting interaction and joint engagement in the lab activities. While the study focuses on the labs, it is important to note that the teaching presence in the course was also—and potentially more so—enabled through in-class lectures and online consultation sessions. These forms of direct instruction facilitated the learning process in combination with the online labs. Even though students reported an initial unfamiliarity with simulations, the setup of the course largely provided the features of teaching presence, such as direct instructions and facilitating discourse during the lab sessions as well as enhanced reflective and sustained communication through the paired work and consultation sessions, with students noting that "help from teachers has always been available via email or consultation sessions." However, a technically demanding learning environment might always pose a challenge to students, making the teaching presence extraordinarily important.

The inherent complexity of the teacher's role in a learning environment with both on-campus and remote students was apparent as achieving a balance in supporting the two student groups was a challenge. Our results, though mixed, are in line with research in blended synchronous learning that points at the increased cognitive load for teachers [74] and the challenge to keep learner engagement high in both cohorts [75]. They must concurrently navigate physical and digital spaces, engaging both on-campus and remote students while creating a learning environment for all. The pedagogical complexity in this type of learning environment poses challenges for the instructional design and organization. Co-teaching is one approach that can improve the teaching presence in a hybrid setting [76]. In such an approach, one teacher focuses on the on-campus students and the other on the remote students. In addition to co-teaching, teachers may also use technology to create collaborative virtual spaces where students can actively participate in discussions, seek clarifications, and receive timely feedback. This would further strengthen the teaching presence.

The interaction between teaching presence and cognitive presence is evident in our research. It is complex and influenced by many factors, including the students themselves. This can be seen through the varying interpretations of teacher support within the same course. Intentionally crafted pedagogical methods, such as encouraging students to "figure out [a] problem all by themselves," as described by students, can occasionally cause stress and frustration among students and ultimately impact their ability to learn. This observation aligns with previous research on desirable and undesirable challenges. For example, [71] argue that teachers should try to find the right type and number of desirable challenges in conjunction with providing support for appropriate coping strategies while avoiding undesirable challenges that might result in a lack of progress and motivation, or an inefficient use of resources. Supporting student learning by a combination of teaching presence and cognitive presence can be achieved through various strategies, such as encouraging reflective and sustained communication through discussion prompts and group activities, offering timely and constructive feedback to students to promote deeper understanding and reflection, and implementing methods for assessing student stress and frustration levels to identify areas where teacher support can be improved.

6.3 | Social Presence in Online Labs

Lastly, we discuss the perceptions of students regarding community building and communication. Social presence is fostered by a hybrid overall course design that combines physical and online interactions. The course's hybrid nature, where students meet both in-person and online, helps create a preexisting level of engagement among participants, built through the in-person lectures early in the course. Activities such as the pair work and synchronous sessions are designed to facilitate open communication and interaction among students, helping them form a CoI and engage in collaborative learning [10].

However, the absence of physical copresence irrespective of lab format presented a challenge to group cohesion for students. Our study shows mixed results, with some students struggling to develop a sense of shared commitment and responsibility, for example, regarding the allocation of responsibilities among peers or aligning different work pace. These tensions between collaborative work and personalized learning needs can impact social presence. Teachers could address this by promoting and discussing the pedagogical approach with students early in the course to align expectations regarding the group work. Furthermore, while the course design incorporates concepts of project and problem-based learning in groups, and therefore can expect benefits of collaborative learning [77], our research has demonstrated that the regulatory and managerial challenges of group work become particularly relevant in the hybrid learning environments, as discussed in [71]. Altogether, our results indicate that social presence is higher in campus labs due to face-to-face interactions with easier communication and collaboration, which helps build interpersonal relationships and a sense of community [78]. Despite the hybrid course design with paired learning setups, maintaining social presence in remote labs and simulations can be challenging and often requires deliberate efforts.

Our research demonstrates the interconnectedness of cognitive, social, and teaching presences within the CoI framework. Specifically, in addition to the aforementioned interplay between teaching and cognitive presence, our results also indicate that students engage in reciprocal assistance in comprehending the course material, with students noting they help "[each other] with what was difficult" and "make sure that both [students] understand everything." This demonstrates the potential of social presence to facilitate cognitive presence through promoting knowledge construction and sensemaking. This is indicative of the dynamics among the three presences, where the course design to some extent enables students to benefit from the entanglement of the presences. These findings are consistent with prior research that has suggested a direct impact of social and teaching presence on cognitive presence within the CoI framework [79, 80] and extend it to the educational context of online labs. In light of this, given the interdependent relationship among the three presences, alongside the critical role played by cognitive and social elements in project or problem-based learning approaches in online labs, we suggest greater attention to be paid to a comprehensive analysis of the three presences to optimize their interplay.

6.4 | Theoretical Implications

In this study, the CoI framework was employed as the conceptual construct because of its orientation toward essential features of online learning. During the examination of students' perceptions of remote labs and simulations, two themes emerged that diverged from the three presences outlined in the CoI framework in its classic form. Firstly, the impact of technology itself on learning. Over the past two decades, technology has experienced significant advancements, consequently elevating its significance and increasing its indispensable role in facilitating education. In this study, technical issues including lagging which affected visual experience, setup problems, faulty connections, the complicity of uploading files, bugs, and program crashes encountered by students significantly influenced their learning experiences, affecting all three presences of the CoI framework. While technology may not directly affect learning per se, technology failure can disrupt students' learning experiences considerably. Thus, the role of technology appears somewhat sidelined within CoI, despite it being a framework extensively applied in online learning research. Research outside CoI has been addressing the role of technology more thoroughly. For example, Kozma [81] shows how the various technological capabilities available to learners can influence their approach to constructing knowledge. Additionally, Swan [82] identifies the profound effects of specific online instruction technologies on student engagement with course content, teacher, and fellow students. In light of the essential role played by technology in engineering education with online labs, we conclude that future research could also benefit from examining learning experiences through more technology-oriented theoretical perspectives such as the Theory of Transactional Distance [83] or the Technology Acceptance Model [84].

Secondly, the limitation of CoI in addressing self-regulated learning skills of students, sometimes referred to as learning presence [85]. The ability of students to self-regulate has an impact on their learning experience, which is consistent with prior research indicating that self-regulated learning skills play a critical role in successful online education [86]. The emphasis on individual differences in self-regulation is reflected in students' varying opinions on collaboration and teacher support. As such, this study posits that self-regulated learning and learners' characteristics should be given closer consideration to attain a more comprehensive understanding of the dynamics within hybrid and fully online learning environments.

6.5 | Practical Implications

The challenge with implications stemming from online lab research lies in its contextual nature, impeding the derivation of universal recommendations. However, based on our findings and the specific context of this study, we propose the following considerations for educators in organizing hybrid lab learning:

1. Adopt a blended approach

Simulations, as explicitly acknowledged by students, offer notable benefits. While students' reported experiences regarding the benefits of remote labs may not be as clear-cut as those of simulations and campus labs, their inclusion alongside simulations in a course remains valuable as they provide increased flexibility and accessibility. This approach aligns well with the needs of modern higher education, which often serves a diverse population of nontraditional students. For instance, while essential lab learning experiences are still facilitated through real hands-on activities, specific concepts can be reinforced using remote labs [12] and simulations [14].

2. Sequence labs thoughtfully

In regard to the concrete organization of campus labs, remote labs, and simulations, our results indicate that simulations are perceived as a valuable preparation for campus and remote labs. Nonetheless, this finding deviates from prior research, which has suggested that the effectiveness of labs may be contingent upon the level of student belief in them [14], and, consequently, that campus labs are introduced early to cultivate confidence in the employment of remote labs or simulations in subsequent instruction. However, our results also noted initial challenges due to unfamiliarity with simulations, underlying the necessity of sufficient scaffolding and tutorials for the technical transition to the new format.

3. Enhance preparation activities

To enhance students' learning experiences in hybrid lab environments, teachers might incorporate activities like guided tutorials or preparatory videos for remote labs and simulations. These resources can help students become more comfortable with the tools and processes, minimizing technical challenges during lab sessions.

4. Integrate simulations beyond labs

Given the perceived high value of simulations, teachers may consider integrating them into their courses as instructional activities more broadly. For instance, simulations could be used to visualize complex concepts, allowing students to interact with the material in different ways.

Additionally, the findings from this study highlight the significant impact of technical challenges on students' learning experiences, particularly in remote labs and simulations. Students reported issues such as visual difficulties, system malfunctions, and simulator inconsistencies, as reflected in comments like, "[It was] a little hard to see what was happening," "It hinders my learning when interrupted due to system malf[unction]," and "My only problem with the simulator was that the speeds differed from that in the lab." These challenges emphasize the importance of considering technology as a key factor when designing online or hybrid labs. Practical measures to mitigate these issues could include improving visual setups by providing high-resolution cameras and optimized lighting in remote labs to ensure clear demonstrations, using reliable and tested simulation software that aligns with physical lab setups and minimizes bugs or speed inconsistencies, offering real-time technical support during labs and ensuring students receive adequate training to use the platforms effectively, and conducting routine technical checks to identify and resolve potential issues before sessions begin. While technology may not directly influence learning per se, its failures can significantly disrupt the learning process and hinder students' experiences. Considering these practical adjustments can help reduce such disruptions and improve student experiences in online or hybrid learning environments.

6.6 | Limitations of This Study

Our research, by examining a course that integrates campus labs, remote labs, and simulations, provides a preliminary foundation for further inquiry into the optimal combination of diverse lab formats to enhance students' lab-based learning experiences. However, in this context, where remote labs solely provide remote access to real components on campus, the setup does not fully capitalize on technology. Further investigation may be conducted to explore alternative types of setups that optimally leverage technological advancements. Moreover, the specific design of our context may limit the transferability of our findings to other settings. However, our findings are likely to transfer well to similar contexts with comparable setups, particularly those involving a combination of various lab formats. For instance, the recommendation of a blended approach combining different types of labs to enhance students' learning experiences may be applicable in other courses or disciplines with similar hybrid setups. Similarly, the theoretical implications of the CoI framework identified in this study are not confined to engineering contexts. They align with and confirm prior research across a variety of disciplines, suggesting broader applicability. Future studies could explore whether these findings are consistent or differ in other contexts to further expand on the insights presented here. Additionally, while our analysis of student reflections on their experiences with different lab formats addresses the research gap on online labs and offers valuable insights, it does not provide empirical evidence of learning outcomes. Future research could include performance data to capture the outcomes associated with these lab formats. Another limitation of this study is that since the reflective writings of the students were often short, sometimes it was difficult to interpret the meaning and references made in the comments. To ensure a well-rounded and reflexive interpretation of the data, the author team jointly engaged in multiple rounds of back-and-forth discussions to analyze the data.

7 | Conclusion

This study examined engineering students' experiences with different lab formats in a logic control course, specifically focusing on campus labs, remote labs, and simulations. The findings underscore the distinct strengths and weaknesses of each format based on the CoI framework. Campus labs were preferred for their hands-on experiences, which fostered stronger cognitive presence. Remote labs, while valuable for their flexibility and accessibility, often faced technical challenges that hindered learning. Simulations provided essential preparation and understanding for campus labs but occasionally struggled to bridge the gap to real-world applications. Overall, a blended approach integrating campus labs, remote labs, and simulations appears promising for enhancing students' learning experiences. However, this requires addressing technical issues and ensuring adequate preparation for the use of online labs, both for students and teachers.

Acknowledgments

We thank our colleague Veronica Olesen for providing course information and facilitating data collection. Our appreciation also goes to Stefan Stenbom for his valuable feedback on the manuscript. Additionally, we appreciate the students who participated in the study. The work was funded by the European Union Erasmus+ program, grant number 2020-1- DE01-KA226-HE-005760. This is gratefully acknowledged.

Ethics Statement

All procedures in the study were conducted in accordance with applicable laws and institutional guidelines for research ethics ensuring strict adherence to ethical principles throughout this study. No personally identifiable or sensitive data were collected, ensuring total participant anonymity. Detailed information about the study was provided to participants, reassuring them of their right to voluntary participation and withdrawal. All participants provided their written informed consent.

Conflicts of Interest

The authors declare no conflicts of interest.

Data Availability Statement

The data that support the findings of this study are available from the corresponding author upon reasonable request.

References

1. A. Hofstein and V. N. Lunetta, "The Laboratory in Science Education: Foundations for the Twenty-First Century," *Science Education* 88 (2004): 28–54, https://doi.org/10.1002/sce.10106.

2. Z. Nedic, J. Machotka, and A. Nafalski, 2003. Remote Laboratories Versus Virtual and Real Laboratories, in: 33rd Annual Frontiers in Education. FIE 2003, IEEE, Westminster, Colorado, USA, 2003: p. T3E_1-T3E_6, https://doi.org/10.1109/FIE.2003.1263343.

3. C. D. Honig, C. C. Sutton, and D. M. Bacal, "Off-Campus But Hands-on: Mail Out Practicals With Synchronous Online Activities During COVID-19," *Education for Chemical Engineers* 39 (2022): 84–93, https://doi.org/10.1016/j.ece.2022.03.004.

4. L. S. Post, P. Guo, N. Saab, and W. Admiraal, "Effects of Remote Labs on Cognitive, Behavioral, and Affective Learning Outcomes in Higher Education," *Computers & Education* 140 (2019): 103596, https://doi.org/10.1016/j.compedu.2019.103596.

5. V. Potkonjak, M. Gardner, V. Callaghan, et al., "Virtual Laboratories for Education in Science, Technology, and Engineering: A Review," *Computers & Education* 95 (2016): 309–327, https://doi.org/10.1016/j.compedu.2016.02.002.

6. R. Heradio, L. De La Torre, D. Galan, F. J. Cabrerizo, E. Herrera-Viedma, and S. Dormido, "Virtual and Remote Labs in Education: A Bibliometric Analysis," *Computers & Education* 98 (2016): 14–38, https://doi.org/10.1016/j.compedu.2016.03.010.

7. S. M. Reeves and K. J. Crippen, "Virtual Laboratories in Undergraduate Science and Engineering Courses: A Systematic Review, 2009–2019," *Journal of Science Education and Technology* 30 (2021): 16–30, https://doi.org/10.1007/s10956-020-09866-0.

8. B. J. Fraser, "5.1 Science Learning Environments: Assessment, Effects and Determinants," *International Handbook of Science Education* 1 (1998): 527–564.

9. D. May, G. R. Alves, A. A. Kist, and S. M. Zvacek, "Online Laboratories in Engineering Education Research and Practice," in *International Handbook of Engineering Education Research*, ed. A. Johri (Routledge, 2023), 28, 1st ed.

10. D. R. Garrison, T. Anderson, and W. Archer, "Critical Inquiry in a Text-Based Environment: Computer Conferencing in Higher Education," *Internet and Higher Education* 2 (1999): 87–105, https://doi.org/10.1016/S1096-7516(00)00016-6.

11. S. Stenbom and M. Cleveland-Innes, "Introduction to the Community of Inquiry Theoretical Framework," in *The Design of Digital Learning Environments: Online and Blended Applications of the Community of Inquiry*, eds. M. F. Cleveland-Innes, S. Stenbom, and D. R. Garrison (Routledge, 2024), 3–25.

12. N. Aliane, R. V. Pastor, and G. V. Mariscal, "Limitations of Remote Laboratories in Control Engineering Education," *International Journal of Online and Biomedical Engineering (iJOE)* 6 (2010): 31, https://doi.org/10.3991/ijoe.v6i1.1131.

13. J. E. Corter, S. K. Esche, C. Chassapis, J. Ma, and J. V. Nickerson, "Process and Learning Outcomes From Remotely-Operated, Simulated,

and Hands-on Student Laboratories," *Computers & Education* 57 (2011): 2054–2067, https://doi.org/10.1016/j.compedu.2011.04.009.

14. J. Ma and J. V. Nickerson, "Hands-on, Simulated, and Remote Laboratories: A Comparative Literature Review," *ACM Computing Surveys* 38 (2006): 7, https://doi.org/10.1145/1132960.1132961.

15. X. Chen, G. Song, and Y. Zhang, "Virtual and Remote Laboratory Development: A Review," in *Earth and Space 2010*, ed. G. Song and R. B. Malla (American Society of Civil Engineers, 2010), 3843–3852, https://doi.org/10.1061/41096(366)368.

16. Z. Lei, H. Zhou, W. Hu, et al., "Modular Web-Based Interactive Hybrid Laboratory Framework for Research and Education," *IEEE Access* 6 (2018): 20152–20163, https://doi.org/10.1109/ACCESS.2018.2821713.

17. L. Rodriguez-Gil, J. Garcia-Zubia, P. Orduna, and D. Lopez-de-Ipina, "Towards New Multiplatform Hybrid Online Laboratory Models," *IEEE Transactions on Learning Technologies* 10 (2017): 318–330, https://doi.org/10.1109/TLT.2016.2591953.

18. K. M. Enneking, G. R. Breitenstein, A. F. Coleman, J. H. Reeves, Y. Wang, and N. P. Grove, "The Evaluation of a Hybrid, General Chemistry Laboratory Curriculum: Impact on Students' Cognitive, Affective, and Psychomotor Learning," *Journal of Chemical Education* 96 (2019): 1058–1067, https://doi.org/10.1021/acs.jchemed.8b00637.

19. T. Lynch and I. Ghergulescu, "Review of Virtual Labs as the Emerging Technologies for Teaching STEM Subjects." *INTED2017 Proceedings* (IATED, 2017), 6082–6091.

20. J. West and A. Veenstra, "Cane Toad or Computer Mouse? Real and Computer-Simulated Laboratory Exercises in Physiology Classes," *Australian Journal of Education* 56 (2012): 56–67, https://doi.org/10.1177/000494411205600105.

21. D. I. Lewis, "The Pedagogical Benefits and Pitfalls of Virtual Tools for Teaching and Learning Laboratory Practices in the Biological Sciences," *Higher Education Academy: STEM* (2014): 1–30.

22. A. S. Shidiq, A. Permanasari Hernani, and S. Hendayana, "Chemistry Teacher Responses to Learning in the COVID-19 Outbreak: Challenges and Opportunities to Create Innovative Lab-Work Activities," *Journal of Physics: Conference Series* 1806 (2021): 012195, https://doi.org/10.1088/1742-6596/1806/1/012195.

23. R. G. Hadgraft and A. Kolmos, "Emerging Learning Environments in Engineering Education," *Australasian Journal of Engineering Education* 25 (2020): 3–16, https://doi.org/10.1080/22054952.2020.1713522.

24. C. Zhu, "Student Satisfaction, Performance, and Knowledge Construction in Online Collaborative Learning," *Journal of Educational Technology & Society* 15 (2012): 127–136.

25. M. A. Bochicchio and A. Longo, "Hands-on Remote Labs: Collaborative Web Laboratories as a Case Study for IT Engineering Classes," *IEEE Transactions on Learning Technologies* 2 (2009): 320–330, https://doi.org/10.1109/TLT.2009.30.

26. X. Hu, H. Le, A. G. Bourgeois, and Y. Pan, "Collaborative Learning in Cloud-Based Virtual Computer Labs." *2018 IEEE Frontiers in Education Conference (FIE)* (San Jose, CA, USA: IEEE, 2018), 1–5, https://doi.org/10.1109/FIE.2018.8659018.

27. L. S. Vygotsky and M. Cole, *Mind in Society: Development of Higher Psychological Processes* (Harvard University Press, 1978).

28. J. Dewey, *How We Think* (Dover Publications, 1933).

29. C. S. Peirce, "The Fixation of Belief." in *Philosophical Writings of Peirce*, eds. C. S. Peirce and J. Buchler (Courier Dover Publications, 1955).

30. M. Lipman, *Thinking in Education* (Cambridge University Press, 1991). 1st ed.

31. R. Garrison, *E-Learning in the 21st Century: A Community of Inquiry Framework for Research and Practice* (Routledge, 2017), 3rd ed.

32. K. Swan, "Teaching and Learning in Post-Industrial Distance Education." in *An Introduction to Distance Education*, eds. M. F. Cleveland-Innes and D. R. Garrison (Routledge, 2020), 67–89, 2nd ed, https://doi.org/10.4324/9781315166896.

33. N. D. Vaughan, M. Cleveland-Innes, and D. R. Garrison, *Teaching in Blended Learning Environments: Creating and Sustaining Communities of Inquiry* (Athabasca University Press, 2013).

34. K. Kozan and S. Caskurlu, "On the Nth Presence for the Community of Inquiry Framework," *Computers & Education* 122 (2018): 104–118, https://doi.org/10.1016/j.compedu.2018.03.010.

35. D. R. Garrison and J. B. Arbaugh, "Researching the Community of Inquiry Framework: Review, Issues, and Future Directions," *Internet and Higher Education* 10 (2007): 157–172.

36. C. Xin, "A Critique of the Community of Inquiry Framework," *Journal of Distance Education* 26 (2012): 1–15.

37. Y. Zhang, C. Stöhr, S. S. Jämsvi, and J. Kabo, "Considering the Community of Inquiry Framework in Online Engineering Education - A Literature Review," *Journal of Higher Education Theory and Practice* 23, no. 6 (2023): 55–68, https://doi.org/10.33423/jhetp.v23i6.5973.

38. Y. Z. Olpak, "Community of Inquiry Framework: Research Trends Between 2000-2020," *Online Learning* 26, no. 1 (2022): 350–368, https://doi.org/10.24059/olj.v26i2.2737.

39. J. B. Arbaugh, A. Bangert, and M. Cleveland-Innes, "Subject Matter Effects and the Community of Inquiry (CoI) Framework: An Exploratory Study," *Internet and Higher Education* 13 (2010): 37–44, https://doi.org/10.1016/j.iheduc.2009.10.006.

40. A. Biglan, "The Characteristics of Subject Matter in Different Academic Areas," *Journal of Applied Psychology* 57 (1973): 195–203.

41. P. Gorsky, A. Caspi, A. Antonovsky, I. Blau, and A. Mansur, "The Relationship Between Academic Discipline and Dialogic Behavior in Open University Course Forums," *International Review of Research in Open and Distributed Learning* 11 (2010): 49–72, https://doi.org/10.19173/irrodl.v11i2.820.

42. J. B. Arbaugh, "Does the Community of Inquiry Framework Predict Outcomes in Online MBA Courses?," *International Review of Research in Open and Distance Learning* 9, no. 2 (2008): 1–21, https://doi.org/10.19173/irrodl.v9i2.490.

43. S. Caskurlu, Y. Maeda, J. C. Richardson, and J. Lv, "A Meta-Analysis Addressing the Relationship Between Teaching Presence and Students' Satisfaction and Learning," *Computers & Education* 157 (2020): 103966, https://doi.org/10.1016/j.compedu.2020.103966.

44. J. Choo, N. Bakir, N. I. Scagnoli, B. Ju, and X. Tong, "Using the Community of Inquiry Framework to Understand Students' Learning Experience in Online Undergraduate Business Courses," *TechTrends* 64 (2020): 172–181, https://doi.org/10.1007/s11528-019-00444-9.

45. J. L. F. Choy and C. L. Quek, "Modelling Relationships Between Students' Academic Achievement and Community of Inquiry in an Online Learning Environment for a Blended Course," *Australasian Journal of Educational Technology* 32, no. 4 (2016): 106–124, https://doi.org/10.14742/ajet.2500.

46. C. Hostetter, "Community Matters: Social Presence and Learning Outcomes," *Journal of the Scholarship of Teaching and Learning* 13 (2013): 77–86.

47. Y. J. Joo, K. Y. Lim, and E. K. Kim, "Online University Students' Satisfaction and Persistence: Examining Perceived Level of Presence, Usefulness and Ease of Use as Predictors in a Structural Model," *Computers & Education* 57 (2011): 1654–1664, https://doi.org/10.1016/j.compedu.2011.02.008.

48. J. Lim and J. C. Richardson, "Predictive effects of Undergraduate Students' Perceptions of Social, Cognitive, and Teaching Presence on Affective Learning Outcomes According to Disciplines," *Computers & Education* 161 (2021): 104063, https://doi.org/10.1016/j.compedu.2020.104063.

49. J. C. Richardson, Y. Maeda, J. Lv, and S. Caskurlu, "Social Presence in Relation to Students' Satisfaction and Learning in the Online Environment: A Meta-Analysis," *Computers in Human Behavior* 71 (2017): 402–417, https://doi.org/10.1016/j.chb.2017.02.001.

50. G. Kim and R. Gurvitch, "Online Education Research Adopting the Community of Inquiry Framework: A Systematic Review," *Quest* 72 (2020): 395–409.

51. H. Baytiyeh, "Progreen Online Engineering Diploma in the Middle East: Assessment of the Educational Experience," *European Journal of Engineering Education* 43 (2018): 264–277.

52. K. A. Douglas, A. C. Johnston, J. P. Martin, T. Short, and R. A. Soto-Pérez, "How Engineering Instructors Supported Students During Emergency Remote Instruction: A Case Comparison," *Computer Applications in Engineering Education* 30 (2022): 934–955.

53. B. H. Guo, M. Milke, and R. Jin, "Civil Engineering Students' Perceptions of Emergency Remote Teaching: A Case Study in New Zealand," *European Journal of Engineering Education* 47 (2022): 679–696.

54. R. Nihlawi, H. El-Baz, and C. Gunn, "Engineering Students' Perceptions of Flipped Learning: Benefits, Challenges and Recommendations," in *2018 Advances in Science and Engineering Technology International Conferences (ASET)* (IEEE, 2018), 1–6.

55. D. Annand, "Limitations of the Community of Inquiry Framework," *International Journal of E-Learning & Distance Education* 34 (2019): 15.

56. J. Lim and J. C. Richardson, "Considering How Disciplinary Differences Matter for Successful Online Learning Through the Community of Inquiry Lens," *Computers & Education* 187 (2022): 104551, https://doi.org/10.1016/j.compedu.2022.104551.

57. E. P. Purwandari, K. Junus, and H. B. Santoso, "Exploring E-Learning Community of Inquiry Framework for Engineering Education," *International Journal of Instruction* 15 (2022): 619–632.

58. T. S. N. Rachmawati, C. R. Priadi, F. H. Sagitaningrum, et al., "Comparison of Online Group Discussion and Class Discussion Learning for a Soil Mechanics Class," *IOP Conference Series: Materials Science and Engineering* 830 (2020): 032056, https://doi.org/10.1088/1757-899X/830/3/032056.

59. E. Szeto, "Community of Inquiry as an Instructional Approach: What Effects of Teaching, Social and Cognitive Presences Are There in Blended Synchronous Learning and Teaching?," *Computers & Education* 81 (2015): 191–201, https://doi.org/10.1016/j.compedu.2014.10.015.

60. J. C. Libarkin and J. P. Kurdziel, "Research Methodologies in Science Education: The Qualitative-Quantitative Debate," *Journal of Geoscience Education* 50 (2002): 78–86.

61. V. Braun and V. Clarke, "Using Thematic Analysis in Psychology," *Qualitative Research in Psychology* 3 (2006): 77–101, https://doi.org/10.1191/1478088706qp063oa.

62. V. Olesen, C. Stöhr, M. Enelund, and J. Malmqvist, "Learning Mechatronics Using Digital Live Labs," *Proceedings of the 18th International CDIO Conference* (2022): 831–847.

63. V. Braun and V. Clarke, "Thematic Analysis: A Practical Guide," *Sage* (2022).

64. A. Corden and R. Sainsbury, *Using Verbatim Quotations in Reporting Qualitative Social Research: Researchers' Views* (University of York, 2006).

65. S. H. Sung, C. Li, X. Huang, and C. Xie, "Enhancing Distance Learning of Science—Impacts of Remote Labs 2.0 on Students' Behavioural and Cognitive Engagement," *Journal of Computer Assisted Learning* 37 (2021): 1606–1621, https://doi.org/10.1111/jcal.12600.

66. J. E. Corter, J. V. Nickerson, S. K. Esche, C. Chassapis, S. Im, and J. Ma, "Constructing Reality: A Study of Remote, Hands-on, and Simulated Laboratories," *ACM Transactions on Computer-Human Interaction* 14 (2007): 7, https://doi.org/10.1145/1275511.1275513.

67. T. Sitzmann, K. Ely, B. S. Bell, and K. N. Bauer, "The Effects of Technical Difficulties on Learning and Attrition During Online Training," *Journal of Experimental Psychology: Applied* 16 (2010): 281–292, https://doi.org/10.1037/a0019968.

68. S. Sheikhi, K. Bronstein, E. Mayer, R. Langer, A. Reise, and C. Stöhr, "Blended Laboratories for Joining Technology," *Proceedings of the 19th International CDIO Conference* (2023): 166–178.

69. E. Bartocci, R. Singh, F. B. von Stein, et al., "Teaching Cardiac Electrophysiology Modeling to Undergraduate Students: Laboratory Exercises and GPU Programming for the Study of Arrhythmias and Spiral Wave Dynamics," *Advances in Physiology Education* 35 (2011): 427–437, https://doi.org/10.1152/advan.00034.2011.

70. L. K. Smetana and R. L. Bell, "Computer Simulations to Support Science Instruction and Learning: A Critical Review of the Literature," *International Journal of Science Education* 34 (2012): 1337–1370, https://doi.org/10.1080/09500693.2011.605182.

71. M. O'Connell, T. Adawi, H. D. Trefna, A. Ström, and C. Stöhr, 2021. Challenge Episodes and Coping Strategies in Undergraduate Engineering Research, in: SEFI 49th Annual Conference: Blended Learning in Engineering Education: Challenging, Enlightening – and Lasting? pp. 1071–1079, accessed October 7, 2024, https://research.chalmers.se/en/publication/528334.

72. C. Stöhr, C. Demazière, and T. Adawi, "The Polarizing Effect of the Online Flipped Classroom," *Computers & Education* 147 (2020): 103789, https://doi.org/10.1016/j.compedu.2019.103789.

73. L. Hajibayova, "Students' Viewpoint: What Constitutes Presence in an Online Classroom?," *Cataloging & Classification Quarterly* 55 (2017): 12–25, https://doi.org/10.1080/01639374.2016.1241972.

74. M. Bower, J. Kenney, B. Dalgarno, M. J. W. Lee, and G. E. Kennedy, "Blended Synchronous Learning: Patterns and Principles for Simultaneously Engaging Co-Located and Distributed Learners," *Proceedings of the 30th Ascilite Conference (2013)*: 92–102

75. A. Raes, L. Detienne, I. Windey, and F. Depaepe, "A Systematic Literature Review on Synchronous Hybrid Learning: Gaps Identified," *Learning Environments Research* 23 (2020): 269–290, https://doi.org/10.1007/s10984-019-09303-z.

76. R. N. Rooks, J. Scandlyn, K. Pelowich, and S. Lor, "Co-Teaching Two Interdisciplinary Courses in Higher Education," *International Journal for the Scholarship of Teaching and Learning* 16 (2022): 1–12, https://doi.org/10.20429/ijsotl.2022.160208.

77. H. Jeong, C. E. Hmelo-Silver, and K. Jo, "Ten Years of Computer-Supported Collaborative Learning: A Meta-Analysis of CSCL in STEM Education During 2005–2014," *Educational Research Review* 28 (2019): 100284, https://doi.org/10.1016/j.edurev.2019.100284.

78. Z. Zhan and H. Mei, "Academic Self-Concept and Social Presence in Face-to-Face and Online Learning: Perceptions and Effects on Students' Learning Achievement and Satisfaction Across Environments," *Computers & Education* 69 (2013): 131–138, https://doi.org/10.1016/j.compedu.2013.07.002.

79. D. R. Garrison, M. Cleveland-Innes, and T. S. Fung, "Exploring Causal Relationships Among Teaching, Cognitive and Social Presence: Student Perceptions of the Community of Inquiry Framework," *Internet and Higher Education* 13 (2010): 31–36, https://doi.org/10.1016/j.iheduc.2009.10.002.

80. Z. Ma, J. Wang, Q. Wang, L. Kong, Y. Wu, and H. Yang, "Verifying Causal Relationships Among the Presences of the Community of Inquiry Framework in the Chinese Context," *International Review of Research in Open and Distributed Learning* 18 (2017): 213–230, https://doi.org/10.19173/irrodl.v18i6.3197.

81. R. B. Kozma, "Will Media Influence Learning? Reframing the Debate," *ETR&D* 42 (1994): 7–19, https://doi.org/10.1007/BF02299087.

82. K. Swan, 2005. Interface Matters: What Research Says About the Mediating Effects of Course Interfaces, in: 20th Annual Conference on

Distance Teaching and Learning. The Board of Regents of the University of Wisconsin System. https://www.uwex.edu/disted/conference.

83. M. G. Moore, "Theory of Transactional Distance." in *Theoretical Principles of Distance Education*, ed. D. Keegan (Routledge, 1993), 22–38.

84. F. Davis, 1985. A Technology Acceptance Model for Empirically Testing New End-User Information Systems: Theory and Results, PhD Thesis, MIT Sloan School of Management.

85. P. Shea and T. Bidjerano, "Learning Presence: Towards a Theory of Self-Efficacy, Self-Regulation, and the Development of a Communities of Inquiry in Online and Blended Learning Environments," *Computers & Education* 55 (2010): 1721–1731, https://doi.org/10.1016/j.compedu.2010.07.017.

86. P. Shea and T. Bidjerano, "Learning Presence as a Moderator in the Community of Inquiry Model," *Computers & Education* 59 (2012): 316–326, https://doi.org/10.1109/FIE.2003.1263343.

Appendix A

Questions and Prompts for Reflection

Student Experiences of Remote Labs and Simulations

We would like to better understand how you experienced the online labs in comparison with traditional lab exercises. This relates both to the simulations and the remote lab. Your reflection will only be used for research purposes and will have no impact on your course result. By answering these questions, you agree to participate in this study and that quotes from your answers can be used anonymously in academic publications.

Please answer the questions below on the flip side of this paper. You are welcome to answer in English or Swedish.

1. In a few sentences, please reflect upon your experiences of the remote lab (s), particularly in comparison to labs conducted on campus.

Please consider:

• How hard or easy was it to conduct the labs online compared to campus?

• How did the remote setup enhance or hinder your learning?

• How did you organize the collaboration with your peer?

• How did you experience the collaboration?

• How did you experience the support from the teacher(s)?

2. In a few sentences, please reflect upon your experiences of the simulations in the project work.

Please consider:

• How hard or easy was it to work with the simulators?

• How did the simulations enhance or hinder your learning in the lab?

• How did you organize and experience the collaboration with your peer?

• How did you experience the support from the teacher(s)?

3. Do you generally think simulations and/or remote labs are a promising way forward for engineering education? Why or why not?