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Switching from Hands-on Labs to Exclusively Online Experimentation in Electrical and Computer Engineering Courses

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Amy Ingalls is an instructional designer with the University of Georgia Office of Online Learning. She holds a Master of Education in Instructional Design and an Education Specialist in Library Media. Amy has extensive experience developing, designing, and supporting impactful online courses at the undergraduate and graduate levels. Her work focuses on applying Learning Experience Design to create inclusive online educational environments.

Switching from hands-on labs to exclusively online experimentation in electrical and computer engineering courses

1. Introduction

The COVID-19 global pandemic forced universities to suspend face-to-face instruction, prompting faculty to rapidly transition to online instruction. While the transition to online instruction is difficult for many instructors in traditional courses, it is a unique challenge for engineering faculty who are also required to deliver alternative laboratory experiences. At the University of Georgia, 70% of the Electrical Engineering (EE) and Computer Systems Engineering (CSE) required courses include hands-on lab components that are integral to meeting course learning outcomes. Due to COVID-19, almost all courses have transitioned to online instruction in 2020. This transition also included the translation of hands-on labs into online lab experiences, which is especially difficult because of the highly interactive nature of such lab course components.

For the study presented in this paper, the goal is to investigate faculty adoption and student success in traditional in-class lab courses that have rapidly transitioned to online. To that end, this research closely examines the socio-technical realities of online experimentation and the rapid transition from face-to-face to online labs. The study explores the impact of online lab adoption on faculty who must satisfy lab-based experiential learning outcomes and students who must engage in lab exercises more independently. The purpose of this paper is to present our approach to transitioning to the online mode for labs, as well as our research approach and beginning findings from two perspectives: the faculty and the student perspective. Within the study user experience (UX) is a third perspective, but it is not the focus of this paper. Finally, we explain the future steps of our project to expand our understanding of these perspectives in ongoing research.

2. Online laboratories in higher education

Recent innovations in online education and the need for lab exercises as part of competence development in STEM education have led to the development of online laboratory solutions - termed online labs. Those tools include remote–physically real existing equipment used over distance, augmented reality (real existing labs with VR add-ons), and virtual labs–a software-based fully virtual lab, often through simulation [1-7]. Online laboratories have gained prominence because they have the potential to overcome some drawbacks of classical, hands-on labs such as equipment, time, capacity, or infrastructure constraints [7, 8]. Furthermore, if used in addition to and not as a substitute for hands-on labs, online laboratory solutions have the potential to offer additional, self-guided lab interaction to the students and can support individual learner needs.

In terms of student learning, studies demonstrate that, under certain conditions, online labs have equal or potentially better impacts on learning outcomes compared to traditional hands-on labs [1, 8-12]. Other studies show that online laboratories can be efficient tools for engaging engineering students with lab-based learning experiences and practical tools, stimulating autonomous learning and offering practical problem-solving experience, improving student motivation, and overcoming organizational shortcomings in higher education institutions [13-15].

However, Brinson also observed that research results are in parts contradicting, that current studies show a large variability in the measured outcomes and that research in this field is done by different areas and subdisciplines [1, 2]. Hence, it is necessary to expand the research activities and the body of knowledge in this field, not only for the current situation with the pandemic but also for the future of online education and online experimentation. For the presented study, a threefold research perspective is considered. In initially separate research emphases, our project team is looking at the faculty, student, and UX perspective. Based on these results, it will be possible to develop a more holistic understanding of the introduction of online experimentation, especially in the engineering education field.

3. Study-related course context and online laboratories

While many Electrical Engineering and Computer Engineering programs were able to transition their laboratory instruction to take-home kits coupled with a laptop and USB connected electronic testing module, the lack of a mandatory laptop policy at our institution meant that we could not reliably depend upon our students to have ready access to either a laptop or the USB connected electronic test equipment. Thus, we determined that the idea of using simulation coupled with a take-home kit was not a viable approach for our implementation of remote laboratory instruction. Fortunately, several faculty members had been working with online experimentation technologies prior to the impact of COVID-19 on face-to-face lab instruction. In fact, based on positive experiences in earlier pilot studies [16, 17], faculty had already decided to incorporate limited use of remote labs in their face-to-face course delivery models. For those remote labs, the students are free to either use their personal computer or the publicly available computer stations at the College. For our context, this is a key advantage over the approach with take-home lab kits, for which students need personal computer infrastructure at home. Hence, we were ideally positioned to build on these experiences while transitioning to online instruction in response to the global pandemic.

3.1 Curricular context for the online experimentation experience

It is worth stressing that the online remote lab experience developed in our pilot studies and the additional platforms that we have deployed as a part of the study detailed here are not simulation-based lab experiences. They are in fact, remotely reconfigurable hardware platforms that allow students to emulate the experience of building a circuit on a breadboard and then testing that circuit with remotely accessible electronic measure systems. Thus, while students are working through a computer interface, to execute the remote lab activities, they are not producing a digital simulation file that can be shared between students. Rather, each student must log on to the remote system and complete the steps of the lab activity independently.

The main focus for the work presented here was the development and impact study of a fully online version of our combined lecture/lab summer term course - ECSE 2170 Fundamentals of Circuit Analysis. Skills learned in this course include both analytical (required for the design and evaluation of circuits) and hands-on (building, testing, and debugging circuits) parts. The course serves ~350 students annually, including ~75 students during the summer term. Under normal face-to-face instruction, this course covers basic circuit analysis concepts in a lecture setting and then re-enforces those concepts through a series of lab activities that require students to use circuit simulation software (ex. PSPICE, MultiSim etc.) to simulate circuits before building the circuits using discrete components on a breadboard and then testing using standard electronic test equipment.

3.2 Online labs for EE and CSE students

We implement two different remote lab solutions for EE and CSE students during self-paced online lab sessions. Namely, we introduced the VISIR lab platform [18] and netCIRCUITlabs from Emona Instruments [19]. Both remote labs offer suitable online lab environments for different educational levels of EE and CSE courses.

The VISIR workbench is equipped with a web interface that enables students to use familiar benchtop instruments from their computer screens, such as a virtual breadboard, multimeter, and basic electronic components (see Fig. 1 and YouTube video). The goal of this representation is to reproduce tactile learning by emulating the required operating functions, such as moving components and rotating instrument knobs.

Figure 1: VISIR web interface with the breadboard, digital multimeter, and oscilloscope

The Emona TIMS netCIRCUITlabs, used for the first time this summer term, offers online access to multiple students, simultaneously, for controlling and measuring real electronics circuits. The system is accessible via a web browser and covers a range of experiments such as AC amplifiers, feedback circuits, and differential amplifiers. The lab equipment comprises a control unit and several switchable boards for different experiments (see Fig. 2 and YouTube video).

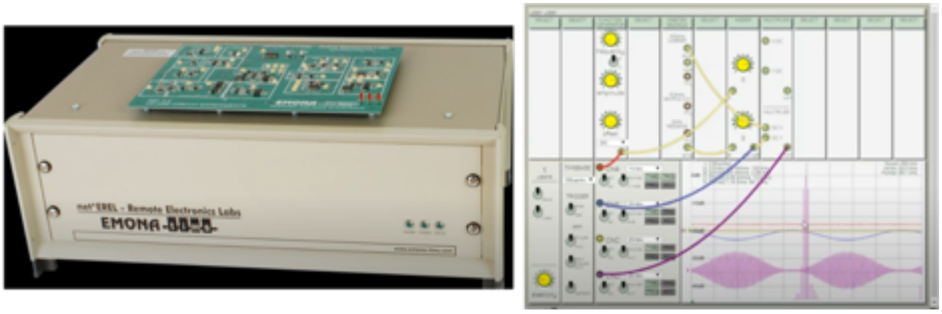

Figure 2: netCIRCUTISlabs control unit with experimentation board and exemplary user interface

For the implementation of online lab modules presented in this study, students were able to use a web interface to access circuit simulation software. The circuits were then implemented through a web interface with one of the aforementioned remote lab platforms. It is worth noting that while the manipulation of circuit elements occurs through a virtual interface, in both remote lab platforms, the users are manipulating real physical circuit elements and making real electrical measurements. While this approach lacks the tactile feel of pushing a component into a breadboard or attaching a measurement probe to a component lead, it retains all of the conceptual challenges associated with how a student convert a circuit diagram to a breadboard layout and how measurements probes are appropriately connected and referenced to complete an electrical measurement of circuit performance.

Finally, it is worth noting that the web interface used to access these remote lab platforms makes the deployment of this technology in an online lab setting very natural. Where a face-to-face lab activity allows the instructor to engage with a student by demonstrating at their "bench" the appropriate steps for building and testing a circuit, the web interface used in these platforms is readily shared in a Zoom™ session allowing the instructor to both demonstrate to students how the lab is executed and to observe the students' shared screen to see how they are using the web interface while executing the lab's steps. Further, by using screen sharing through a Zoom™ session, it is possible to implement lab practicums in much the same way that you would do in a face-to-face lab setting. Finally, while the combination of Zoom™ and the web interface of these online lab platforms enables a very natural replacement for face-to-face lab interactions between faculty and student (or students and students), the 24/7 accessibility of these remote tools means that students are able to access the lab resources and practice with the concepts at times when a normal lab facility might not be available (i.e. after hours or even during a pandemic related shutdown).

4. Study design

Concurrent with the development of online materials for the course, we developed an approach to investigate the impact of using remote labs from three perspectives: (1) faculty's perspective by looking at faculty resistance and adoption, (2) student motivation and self-regulation perspective, and (3) a UX perspective that concentrates on the interactions and the online interface. Informed by theoretical frameworks of diffusion of innovation [20], the propagation paradigm [21], student cognitive and emotional engagement [22], and user-centered design [23], each perspective is investigated through mixed methods research approach. The faculty and the student perspective form the main focus of this paper and will be discussed in the following. The UX perspective will be discussed in the last chapter as part of future work.

The research activity started in summer 2020 with study-related pilot testing in the Fundamentals of Circuits Analysis course's maymester version. Beginning in Fall 2020, the research team has performed a targeted concept roll-out to logical extensions from the above-named course in the EE and CSE curriculum. Further, the research is expanded on online lab implementation modalities and different hybrid models with face-to-face portions and online experimentation, respectively, depending on the current health regulations for university instruction at the time. Here, the research activities and beginning results from Summer and Fall 2020 will be discussed.

4.1 Faculty perspective

It was of focal importance for the research team to develop a holistic view on this introduction process and also include the faculty perspective in terms of rejection or adoption of the newly introduced technology. Looking at the afore-mentioned case studies in literature it should be noted that many research and evaluation studies in this area are performed by the same team that developed the examined technology. Even though this is not an issue per se, this approach might come with the risk of lacking the perspective of faculty who were not part of the development team and have a new and fresh perspective on the technology. However, the disrupting pandemic situation was totally different in that regard. The rapid shift from in-class to online instruction and the necessity to also bring lab experiences online led to many faculty adopting new instructional technologies that they either did not develop themselves or would not have introduced to their classroom in regular times. This context served as a perfect opportunity to examine the introduction of new instructional classroom technology for distance education with a diverse group of faculty: those with and without pre-existing experiences and interest in online laboratories. Hence, the research team posed the following research question for this project part: *How do faculty experience a top-down mandated, time-constrained, and rapid transition to exclusively online-based laboratory modules in engineering courses along the continuum of resistance towards the wholesale embrace of educational technologies?*

4.1.1 Research activities

As a research goal, the project team wants to develop an empirically based understanding of faculty characteristics and mindsets that inform the adoption of, or resistance to online experimentation. The rapid, mandated nature of the process in 2020 has been expected to reveal insights that adoption studies in "normal times" cannot provide. As a theoretical model to guide the understanding of technology adoption, the study is applying the Framework of Propagation, which Froyd developed to display the connection of fit, efficacy, and adoption of educational innovation [21]. From this work, it follows that adopted innovations are both highly effective and fit instructional circumstances. To investigate both fit and efficacy, the study uses the Diffusion of Innovation Framework [20, 24, 25]. The Diffusion of Innovation Framework considers how ideas are promulgated and implemented within a target population.

The study includes a mixed-method approach including scales to measure the perceptions of adopting information technology developed by Moore and Benbasat [26, 27] and McCann [28]. However, the beginning results reported here are on the basis of qualitative measures. The qualitative research tools included short, written faculty reflection [29-31]. The reflection prompts were collected via email from each of the lab course instructors every other week during lab course delivery and include a set of overall eleven questions (e.g.: "How did your experience as a course instructor compare to using traditional in-class lab activities with hands-on labs?" or "How would you describe the fit of the online lab with the course audience?"). The questions don't change over the course of the semester. In the future, this picture will be extended by selected faculty interviews, which will happen in Spring 2021 and cannot be included in the description here.

4.1.2 First Results

For Summer 2020 and Fall 2020, 16 filled-out reflection prompts were collected from four different course instructors (two different instructors in Summer 2020 and four instructors in Fall 2020; the Summer instructors are also part of the Fall group). Depending on the individual instructor's schedule and lab portions in the respective courses, the number of returned prompts ranges from one up to five returned prompts per instructor per semester.

Following the diffusion of innovations framework as discussed in [21], each reflection prompt asked the course instructors for an overall rating in terms of fit and efficacy of the used technology in the course. This rating was given again with every new prompt during the semester. Therefore, the results show a timely rating for the latest course deliveries with the help of the VISIR-based and EMONA-based technology. In particular, the course instructors were asked to rate (On a scale from 1 to 10, 1 being "not at all" and 10 being "very much") 1) "the fit of the online lab for your instruction and the course delivery? (fit: the degree to which the online lab is compatible with your instructional context and your pedagogical beliefs)" and 2) "the efficacy of the online lab for your instruction and the course delivery? (efficacy: the degree of relative advantage which the lab holds for improving the student learning)". Fig. 3 shows the Summer and Fall 2020 results for those two questions.

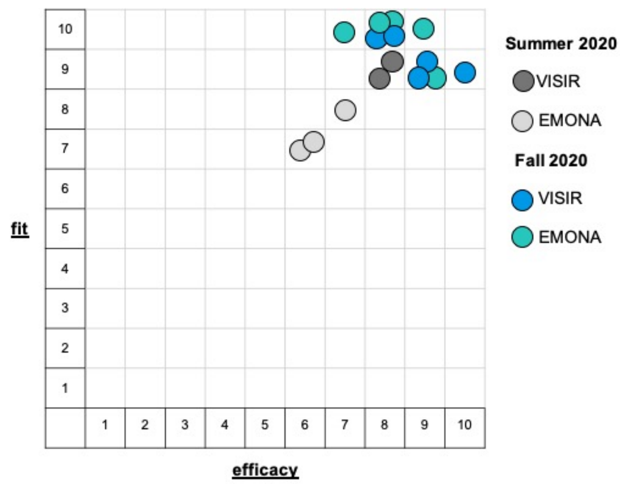

Figure 3: Faculty rating for remote labs' fit and efficacy

Two core messages can be deduced from the shown result. First, the overall rating for fit and efficacy of both introduced technologies is very positive and supportive. As in [21] expressed, technologies, which are rated high on both fit and efficacy, are very likely to be meaningfully adopted, also in the long run. Both systems introduced fall into this very category following the prompts' results. A second message can be seen by comparing the Summer and Fall results. The ratings in Fall are higher than in Summer. Two reasons might play a role here. One explanation could be that the first introduction of both technologies in the online Summer courses may have come with initial technical issues and first-time-user issues based on the instructors' experience, which needed to be solved early on. This assumption could be supported by the fact that one of the summer instructors had pilot experiences with the VISIR system but the EMONA tool was entirely new to both of them. Another way to explain the effect of higher ratings for both technologies in Fall might be that the faculty included in this study are in contact with each other. Hence, the Summer instructors could have shared their first-hand experiences in the form of an internal, collegial introduction process for the remaining fall faculty. Both assumptions so far are supported by further anecdotal observations by the research team but need to be validated by further investigation in order to develop an explicit picture.

A closer look at the remaining reflective prompts' data reveals additional topics of focal interest for further investigation in the project. Directly asked about how the faculty experienced the shift from traditional face-to-face lab courses to online experimentation, the faculty reported mixed results. Setting reported initial technical issues with the technology aside, all faculty expressed their satisfaction with and appreciation for the opportunity to still deliver laboratory class even under the social distancing mandate. One faculty actually described that labs are better done in person, but the online labs allow the students to still achieve the required course outcomes. Especially for freshmen students, the labs are reported to be a good option as they can "play around" with the equipment much easier and longer than in traditional, more time-constrained lab courses. The following quote from one of the prompts supports this and shares further interesting observations:

> *"It requires more preparation, more supporting material, and more instructor effort in activities such as zoom and answering emails, but it is manageable. It pays off because students are allowed more time to play around with the remote lab tools, which plays a big role in learning. On the other hand, students who are less curious do better under a supervised in-person lab environment. In general, remote labs reduce the demand for in-person interactive efforts with students, but in exchange, it increases the demands on the preparation of handouts and lab support materials."*

4.2 Student perspective

As observed by faculty, student experiences in the online labs understandably differ from traditional, in-person lab engagement. Our study also explores the impact of online labs on students who must engage in lab exercises independently. Student cognitive and emotional engagement, important contributors to academic success [22], have been operationalized through two student perspectives, motivation, and self-regulation [32-34]. The research question guiding this student-centered facet is: *How does exclusively online laboratory instruction and online experimentation impact students' learning experiences in terms of engagement, investigated through self-regulation and motivation?*

4.2.1 Research activities

We are investigating this research question through a mixed-methods research approach that uses the Motivated Strategies for Learning Questionnaire (MSLQ) [35] and qualitative interview data collected using a formal interview protocol [36]. Four subscales from the MSLQ were selected for their conceptual basis in motivation or self-regulation and modified slightly for language surrounding online lab experiences. Students respond to each item on a 7-point Likert scale from 1 (not at all true of me) to 7 (very true of me).

4.2.2 First Results

So far, our preliminary analysis offers insight into student attitudes as they begin instruction with online labs. Survey data was collected from 68 students (52 men and 16 women) in the first week of the semester with responses on the motivation and self-regulation questions showing high reliability (see Table 1). Students comprised various engineering majors in the college including mechanical (n = 36), biological (n = 11), electrical (n = 9), computer (n = 8), and agricultural, biochemical, and environmental (n = 4). Most students were later in their studies: they were sophomores (n = 3), juniors (n = 35), or seniors (n = 29).

Table 1. Descriptive statistics for motivation and self-regulation items.

Scale	Mean (SD)	Range	Reliability	Items
Motivation	5.21 (0.92)	4.44–5.72	0.89	14
Self-Regulation	4.84 (0.70)	3.37–5.60	0.78	12

In general, students had nominal motivation for the course, with scale means falling close to what has been seen in other courses [35]. Furthermore, their self-regulation or learning strategies were normal. A variety of factors might influence this report or leave it open to change: if student views were only based on past experience due to unfamiliarity with the online labs, they might be uncalibrated to these new learning experiences.

We briefly explored whether student motivation or self-regulation differed by major, class standing, or gender. We hypothesized that some of these demographic factors might affect student views—for example, electrical engineering students might be more interested in the content or have more adequate strategies since the course was in the department; over time (higher class standing) students might also develop more effective learning strategies.

ANOVA models indicated that neither major nor year had an effect on motivation or self-regulation as students began the semester. Neither did we observe differences among genders on either variable when we conducted independent *t*-tests.

Results of the MSLQ survey seem to indicate students' approach to the online lab course in a typical way. The basis for these scores might have been past experience in traditional labs since students were into their studies. It is also possible that students' expectations were not calibrated to online labs; while many students are familiar with online course modes for instruction, online modes for labs are not as well known. Qualitative data gathered partway through the course seems to affirm students' confidence in the online labs and that they had prepared properly. Much attention was given to preparation to ensure readiness prior to a lab assignment. Students also mentioned the lack of teamwork and low accessibility to professors as a drawback to online labs - a possible explanation for the nominal learning strategies score. Nonetheless, students indicated positive responses when inquired on their interest in enrolling in future online labs.

5. Discussion and future steps

Overall, the initial efforts in using remote labs during the current crisis are well received by both the faculty and the students. Further, the instructors who developed and deployed the remote lab modules found them to be a useful component of their course instruction. Faculty and students appreciate the flexibility of online experimentation and that lab activities can be performed even under the current circumstances. It is noted that online experimentation adds another layer of technology to the lab activity, which must be mastered and integrated into the local learning management system. Further, flexibility comes with a higher demand for student self-guidance abilities. Though the rapid switch to online instruction proved to be challenging, early data shows that the integration of online labs has a likely chance to persist as part of the curriculum, perhaps in combination with hands-on labs. For example, one could think of using online labs as preparation for hands-on labs to better understand both theoretical concepts and basic technical procedures and use face-to-face lab time for more complex activities.

In online learning environments, user experience (UX) is the users' perspective of and response to using the systems. Faculty and students are both users of the interfaces for online labs and experiments. Faculty are responsible to design, implement, demonstrate, and assess online lab experiences; students complete the exercises, navigating the interface to further their understanding. However, a unique contribution of the UX perspective in this research is the holistic examination of how user perceptions, the technological platform or environment, and users resulting actions and behaviors affect learning and engagement in the online labs. The theoretical work underpinning this facet of our research is Gibson's Theory of Affordances [37, 38] that describes these cascading effects from perception to action. While a poorly designed interface can be an obstacle to learning [39], ease of use can affect student collaboration, commitment, and how learning unfolds [40, 41].

The UX focus of our research is under development, with the inclusion of surveys, observations of student actions during lab exercises, and follow-up interviews on the lab experiences. The combination of these methods will allow us to make improvements to implementation, instruction, and hopefully the interfaces for learning through online labs.

Our future work in the project involves ongoing inquiry for each of the three perspectives described above. In particular, we are conducting a more extensive survey of students before and after their course participation to understand changes in student motivation and self-regulation strategies throughout the course. Moreover, formal interviews (both formative and summative) will be conducted to elaborate on both faculty and students' reasons and opinions about the course format. Last, we hope to integrate these faculty and student perspectives to identify success factors in the implementation of online labs.

As we better understand the perspective of each of these stakeholders, faculty and students, and their interactions within the online lab interface, we will continue to identify factors for successful implementation and instruction via these online modes. We believe that such online modes can be a complement to traditional labs, and it is not our intention to make comparisons about which is better or worse but to understand how learning best be introduced in this environment and find out how to improve the affordances that online labs presently offer.

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