Faculty perspectives on transitioning to exclusively online lab classes in electrical and computer engineering

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***Abstract*—This research work-in-progress paper investigates faculty perspectives on the switch to online experimentation modalities in the context of our Fundamentals of Circuit Analysis course that includes online laboratory modules. While online (remote and virtual) laboratories have long been considered promising supplemental educational tools, the risks and challenges associated with delivering online labs have limited the willingness of faculty to adopt these methods. However, the development of knowledge, methodologies, and success factors for effective online laboratory instruction is a critical and timely need. With this work, we develop an evidence-based understanding of the transition from hands-on to online experimentation and its associated challenges for faculty. We furthermore generate fundamental knowledge about online experimentation adoption in engineering programs, which includes the full spectrum of faculty participants (early, later, and "never" adopters). Preliminary results show that the most important aspects for faculty in the context with switching to online labs are scheduling flexibility and individualized support, learning outcome differences, a connection between lecture and the lab, and student engagement.**

Keywords—virtual laboratory, faculty attitudes, online learning

I. Introduction

The COVID-19 global health crisis has forced educators to rapidly shift to online instruction methods. While this effort is difficult for faculty in general, it is particularly challenging for lecturers who deliver hands-on laboratory instruction. In practice, the mandated transition to online instruction meant for faculty who were initially unconvinced of online experimentation's value that they needed to switch nonetheless. This setting can provoke both strong faculty resistance and surprising adoption, thereby making factors of adoption visible and empirically accessible that cannot be investigated under "normal" circumstances. Past studies of online experimentation have been limited in scope, without addressing the complete ecosystem of online experimentation and oftentimes not looking at the faculty as a highly important user group [1-7].

Our work transcended the immediate needs of the crisis by developing an online version of our combined lecture/lab "Fundamentals of Circuit Analysis" course as a context for our research activities. This new course includes a full set of online laboratory modules for exclusively online experimentation and instruction of electrical circuit building. We leveraged the development and deployment of these online labs and integrated online instruction modules to investigate the following research question:

- *How do faculty experience a top-down mandated, time-constrained, and rapid transition to exclusively online-based laboratory modules?*

We are particularly interested in aspects of faculty resistance or wholesale embrace of online experimentation technologies. As a theoretical model to guide our understanding of technology adoption, we apply the diffusion of innovation [8] and the framework of propagation [9], a concept that identifies effectiveness and fit as critical factors in the successful adoption of innovations. To investigate both fit and efficacy, we base our research tools on the Diffusion of Innovation Framework, which further articulates five factors influencing the adoption or rejection of technology: relative advantage, compatibility, complexity, trialability, and observability. To investigate this context, we apply a parallel, mixed-methods approach using online surveys as well as faculty reflection prompts and faculty interviews. Results from the latter will be the main focus of the work presented here. Ultimately, this work is intended to lead to research findings informing our understanding of what faculty needs to successfully adopt and apply online experimentation equipment. These insights will, in the end, lead to a framework for educational technology propagation, specific to online engineering labs and reflecting factors for both efficacy and fit.

II. Prior work

A. Research on virtual online laboratories

Recent innovations in online education and the need for laboratory exercises as part of competence development in STEM education have led to the development of 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 laboratory, often based on simulation), which are subsumed under the term "online laboratories" [10-15]. The COVID-19 situation during the last two years and the swift need to bring instructional settings online, including laboratory classes, accelerated this development and also provoked a peak in the interest in instructional online laboratories [16-18].

In an online lab, students manipulate investigation material, whether physical (remote) or virtual. The effects of this manipulation are observed to gain insight into the relationship between variables in the conceptual model underlying the online lab [19]. As documented in the literature, benefits of online labs include cost-efficiency for laboratory work, flexibility in varying the experience, multiple user access (not necessarily to the same simulations environment but to parallel labs), damage resistance, user safety, and accessibility of experimental setups [20-23]. Drawbacks, meanwhile, include the complex development process and disconnect between the real-world and online experience in terms of the user's seriousness, responsibility, and carefulness [10, 24, 25]. Hence, various 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 experiences, improving student motivation, and overcoming organizational shortcomings in higher education institutions [26-28]. 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 [15]. Furthermore, the current database in this research field still relies mainly on student feedback and perception [1, 4, 6, 29, 30], which is not enough to gain a deep understanding of the efficacy and efficiency of online labs in instructional settings, particularly when it comes to learning outcomes. Furthermore, there is a clearly detectable need to investigate the adoption and implementation process for online experimentation from the faculty perspective. Large parts of the research body do not question faculty members' ability or willingness to apply new instructional online lab technologies. One reason might be that most of the research thus far has been conducted by the lab developers themselves, meaning they were technically able and, potentially even more important, intrinsically motivated to deploy the online lab. Studies focusing on faculty, who don't have this intrinsic motivation are currently very rare to non-existent.

The work-in-progress research presented in this paper tries to fill this gap by explicitly focusing on the faculty side with the goal of gaining a deeper understanding of their perspective. The special situation around COVID in 2020 gave us the opportunity to even work with faculty who previously would not have been tempted to use online labs in general, but were forced by the circumstances. While the mandated switch to wholesale online education can provoke questions about power and the relationship of university administrators and faculty, our focus was on impacts in the learning environment. Specifically, we were interested in how the switch to online instruction in lab courses impacted the faculty's experienced reality of their teaching. This perspective informed our research plan and the chosen methodologies, as explained in the following sections.

III. Research Design and Plan

A. *Study design and methodology*

To investigate the faculty perspective in the above-described context and to answer the posed research question, we chose a primarily qualitative approach in the form of semi-structured faculty interviews. The interview protocol was informed by both i) the framework of propagation developed by Froyd to connect fit, efficacy, and adoption of educational innovation from a faculty perspective [9] and ii) the diffusion of innovation framework [8, 31-33], that articulates factors influencing the adoption or rejection of technology including relative advantage, compatibility, complexity, trialability, and observability (cited from [9]).

We performed in total five interviews with electrical and computer engineering faculty at our college (male=4, female=1). Four faculty members used the online laboratories explained herein, either during Summer 2020 courses or in Fall semester 2020, to deliver electrical engineering courses on circuits building online. One faculty member decided not to use online labs and developed a workaround for their class. However, we still included this faculty member in the interviews to also hear from faculty still critical of online experimentation. In terms of seniority, the interviews ranged from young faculty with less than three years of teaching experience to faculty members with teaching experience longer than ten years. In terms of the instructional context and the pandemic situation, the interviews focused on the Summer term 2020 (fully online, remote teaching) and the Fall term 2020, in which the college applied a rotating hybrid model allowing a fraction of the students in class and the other fraction taking part remotely using online communication technology.

Faculty interviews were performed during Fall 2020 (one) and Spring 2022 (four), and the interview time ranged from 25 minutes to 53 minutes (for 242 minutes total). Before data analysis, we transcribed the interview recordings.

B. *The online laboratories included in this study*

In total, the faculty members used three different educational technologies and types of online laboratories to deliver laboratory-based courses in the area of electrical circuits building online, two remote laboratories, and one full simulation. We included those laboratories in our study as they cover most of the electrical engineering curriculum and form part of the instructional laboratory infrastructure at our college. The labs were typically used 5 to 8 times per semester, depending on the lab and the course context.

1) *The VISIR remote lab*

The VISIR remote lab 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 [34]). The goal of this representation is to reproduce tactile learning by emulating the required operating functions, such as moving components and rotating instrument knobs. As is typical for a remote lab, the students use the virtual user interface on their computer screen as if they were working with real equipment. The connected experimentation unit provides the student with real experiment values.

2) *The EMONA remote lab*

The Emona TIMS netCIRCUITlabs also 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

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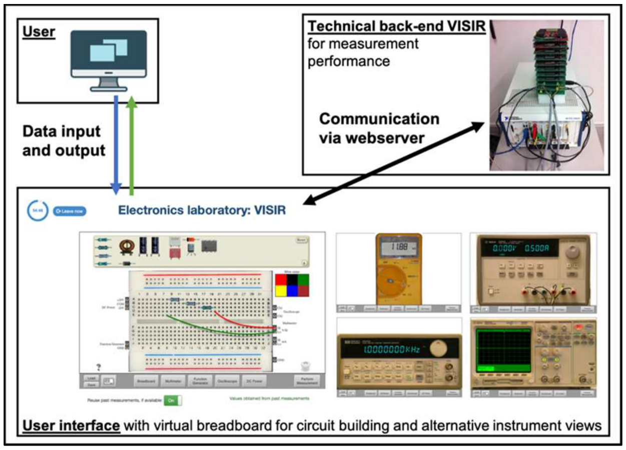

Figure 1: VISIR remote lab conceptual structure

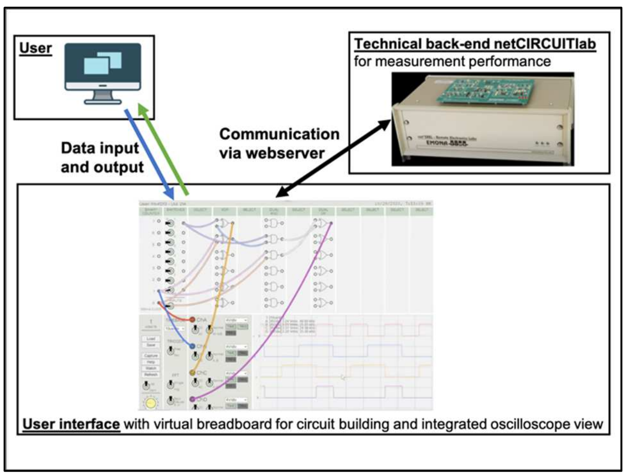

Figure 2: EMONA remote lab conceptual structure

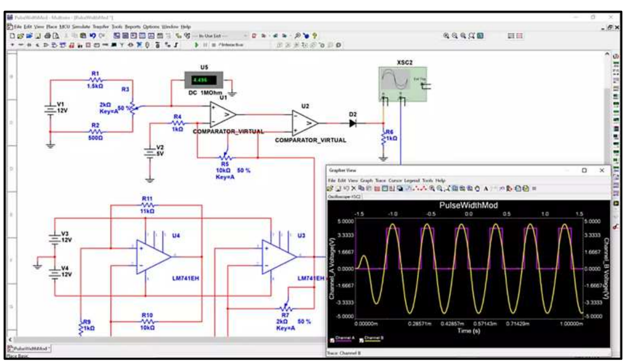

Figure 3: MULTISIM user interface (taken from www.ni.com)

boards for different experiments (see Fig. 2 and [35]). As explained above, for VISIR, the students use the user interface to interact with the equipment, but experimentation data is developed on real equipment.

3) MULTISIM online circuits simulator

The third online lab faculty used to deliver lab courses online was Multisim, an electronic schematic capture and simulation program from National Instruments (NI). This program provides an advanced, industry-standard SPICE simulation environment for circuit building and is widely used in the academic and industry fields [36]. Other than the above-described labs, MULTISIM is purely simulation-based and, hence, is not connected to any physical equipment during the experimentation process.

IV. Data Analysis and Results

In order to analyze the interview data, we transcribed and anonymized interview recordings and numbered the transcripts from F1 to F5. To develop a deep and thorough understanding of the faculty's perspective, we applied a thematic analysis approach in the form of topic coding [37], in which we identified passages across all five interview transcripts that were linked by a common theme or idea allowing us to both highlight the faculty perspective on switching to online lab instruction and answer our research question. In the following, we will display the results developed so far by our qualitative approach.

A. Overarching observations: Comparison to the "real" lab and taking over the student perspective

Before we describe several themes that emerged from coding the data, we want to comment on two aspects that were very clearly visible throughout all five interview transcripts. Firstly, for all faculty interviewed, the concept of describing their experience using online and virtual labs was basically non-existent without a solid comparison to in-person labs. This means that almost every comment the faculty made concerning their experience was built on and compared with their experience using real laboratories. It was not the case that faculty understood the online lab as a new, standalone instructional technology. Still, every advantage, disadvantage, or simply every experience was presented as a result of the comparison between real and virtual laboratories. We decided not to represent this as a theme because this observation transpires clearly in every other theme described in the following. Secondly, it became clear throughout the interview transcripts that the faculty reflected on the switch to online laboratories primarily through the student learning perspective rather than through their own perspective. It was much more the exception that faculty made a clear-cut difference between their own and the student perspective. Most of the time, the faculty expressed thoughts representing the student's perspective, even when asked about their own experience. Even though this observation may not be surprising given that we are talking about an instructional tool, we still felt this worth mentioning.

In the following, we will present and briefly discuss four themes that emerged from the data: Scheduling flexibility and individualized support, learning outcome differences, the connection between lecture and the lab, and student engagement.

B. Theme: Scheduling flexibility and individualized support

We saw that one of the most mentioned advantages of the online labs in the examined context was the flexibility for both professors and students. For professors, it allowed them to track a student's work time in the online lab user management system and give them access to a student's individual progress, which is difficult to measure in a 2-3 hours in-person lab. By the students and professor not being tied down to the set hours of an in-person lab, the professor can take advantage of the entire week to help students who might need it, and students can also reach out based on their individual needs while going through the lab experience. Comments from F2 and F4 stated:

- *"Because when they have flexibility, then they probably will do the lab anytime during the week when they are available. So, the thing is that some of them are active, so when they have questions, they contact me."*
- *"I think the advantage is that they have flexible schedule. And they don't need to worry about the health issue"*

Even though the health issue note was specific to the COVID pandemic, the quote exemplifies other comments that appreciated the independence from the time and space boundaries in regular in-person lab courses.

C. Theme: Learning outcome differences

Oftentimes, online labs and simulations try to depict as accurately as possible what would happen in a real lab. However, there will always be a gap between the real experience and a virtual experience. Remote labs mitigate this issue by using real equipment but still cannot replace the haptic feel and experience of in-person equipment. When it comes to simulations, there is no realistic tolerance in results, so we're left with a schematic that produces perfect numbers. Interviewees acknowledged those differences and referred to different learning outcomes that could be reached in in-person labs and online labs, both remote and virtual. Interviewee F2, for example, said:

- *"The advantage for in-person, definitely, that's hands-on skills. So, if we just talk about understanding the concept, I think, online or in-person labs, they were both do the work. But if you focus on the hand-on skill, especially for our students, Electronic Engineering, we really need a hands-on skill. And then online lab is not doing that."*

D. Theme: Connection between lecture and lab

When a faculty member teaches a lab section, one of the major goals is to have that lab lined up as closely as possible with the lecture content. In the study context, all faculty had this lecture-lab connection well established over the last years. As they were forced to implement online software to run the needed labs, it became much more challenging to relate lab content to the lecture. There were a couple of reasons for this. One reason was the lack of flexibility allowed by the online software in terms of instructional content. The other was the lack of possible complexity when creating an online lab with the used software. Interviewee F1 commented on the lack of complexity, saying:

- *"I envision that for a more advanced course, like a second level circuits class and up, that there would be some more issues arising from that because the topics tend to be more diverse and more sophisticated."*

When looking through the interview data, it became clear that the online labs that were provided by the software strayed from lecture content as the material became more and more complex over the course of the semester, creating a disconnect for the students. Professors tried to modify these labs as much as possible, but the only option seemed to be a simulation-based experience for higher-level circuits classes. Also, it became apparent that faculty tended to try to adapt the lab activity to their course content rather than trying to update their course to match it with the given lab opportunities.

E. Theme: Student engagement with the lab

A major, perhaps the biggest, concern about using online labs as an option was the worry about a lack of student engagement. This worry was based on the assumption that an online lab or simulation gives students the opportunity to not fully engage with the lab's contents or equipment and somehow "sleepwalk" through the entire lab. Interviewee F4 says on this topic:

- *"No matter whether it's an in-person or online class, I think it's important to have interactions, but some students don't realize it."*

When in an in-person lab course atmosphere, everybody in the lab is usually monitored by the faculty and through that forced to engage with the equipment to some extent during the lab period. However, for an online lab or simulation, faculty commented on the possibility that students have the ability to not engage with the course content cognitively and go through the entire course without really understanding the applications of what they are doing, basically by just clicking through the lab.

V. Discussion

As this work is still a work-in-progress, the presented results are preliminary only. We learned so far that faculty experience both advantages and disadvantages in using online laboratories compared to an in-person laboratory session—these advantages and disadvantages match in parts with the existing literature, for example with regard to scheduling the laboratory-based course section and being able to offer more individualized student support. Most prominently, faculty commented on the added flexibility for both faculty and students when switching to online lab instruction. However, this switch also comes with different possibilities and caveats regarding achievable learning outcomes for the students. It became clear that new instructional technology in the form of online labs proved to be a challenge in terms of matching those labs with established course content and curricular structures. Also, the faculty mentioned concerns about the students' cognitive engagement with the course content when doing lab activities at home instead of the in-person lab classes. This potential lack of cognitive engagement clearly needs further investigation.

Looking critically at our chosen approach and methodology, we so far can observe that we were able to understand the faculty experience to a good extent. Themes emerging from the data support and complete existing research but also go beyond the understanding of prior work so far. Future work will be guided by both an even more profound engagement with the data discussed above and follow-up interviews with the same faculty one year later. Those interviews happened in Spring 2022, and we expect to learn even more from this second round. For example, these interviews will give us insights into the faculty perspectives on online laboratories now, at a time when in-person classes are possible again, and whether or how online labs are being integrated with traditional instruction. Contrasting the latest interviews with the interviews displayed in this manuscript will tell us more about what sticks with faculty in terms of online experimentation and, hence, has a chance to prevail in the future.

References

[1] Ayega, D. and A. Khan. *Students Experience on the Efficacy of Virtual Labs in Online Biology*. in *2020 The 4th International Conference on Education and E-Learning*. 2020.

[2] Estriegana, R., J.-A. Medina-Merodio, and R. Barchino, *Student acceptance of virtual laboratory and practical work: An extension of the technology acceptance model.* Computers & Education, 2019. **135**: p. 1-14.

[3] Geisinger, B.N. and D.R. Raman, *Why they leave: Understanding student attrition from engineering majors.* International Journal of Engineering Education, 2013. **29**(4): p. 914-925.

[4] Jona, K., et al., *Are remote labs worth the cost? Insights from a study of student perceptions of remote labs.* International Journal of Online Engineering, 2011. **7**(2): p. 48-53.

[5] Nikolic, S., et al., *Remote, simulation or traditional engineering teaching laboratory: a systematic literature review of assessment implementations to measure student achievement or learning.* European Journal of Engineering Education, 2021. **46**(6): p. 1141-1162.

[6] Stuckey-Mickell, T.A. and B.D. Stuckey-Danner, *Virtual labs in the online biology course: Student perceptions of effectiveness and usability.* MERLOT journal of online learning and teaching, 2007. **3**(2): p. 105-111.

[7] Viegas, C., et al. *Improving students experimental competences using simultaneous methods in class and in assessments*. in *Proceedings of the Second International Conference on Technological Ecosystems for Enhancing Multiculturality*. 2014.

[8] Rogers, E.M., A. Singhal, and M.M. Quinlan, *Diffusion of innovations*, in *An integrated approach to communication theory and research*. 2014, Routledge. p. 432-448.

[9] Froyd, J.E., et al., *From dissemination to propagation: A new paradigm for education developers.* Change: The Magazine of Higher Learning, 2017. **49**(4): p. 35-42.

[10] Faulconer, E.K. and A.B. Gruss, *A review to weigh the pros and cons of online, remote, and distance science laboratory experiences.* International Review of Research in Open and Distributed Learning, 2018. **19**(2).

[11] Heradio, R., et al., *Virtual and remote labs in education: A bibliometric analysis.* Computers & Education, 2016. **98**: p. 14-38.

[12] Ma, J. and J.V. Nickerson, *Hands-on, simulated, and remote laboratories: A comparative literature review.* ACM Computing Surveys (CSUR), 2006. **38**(3): p. 7-es.

[13] May, D., *Cross Reality Spaces in Engineering Education–Online Laboratories for Supporting International Student Collaboration in Merging Realities.* International Journal of Online and Biomedical Engineering (iJOE), 2020. **16**(03): p. 4-26.

[14] Potkonjak, V., et al., *Virtual laboratories for education in science, technology, and engineering: A review.* Computers & Education, 2016. **95**: p. 309-327.

[15] Brinson, J.R., *Learning outcome achievement in non-traditional (virtual and remote) versus traditional (hands-on) laboratories: A review of the empirical research.* Computers & Education, 2015. **87**: p. 218-237.

[16] Allen, T.E. and S.D. Barker, *BME labs in the era of COVID-19: transitioning a hands-on integrative lab experience to remote instruction using Gamified lab simulations.* Biomedical Engineering Education, 2021. **1**(1): p. 99-104.

[17] Gamage, K.A., et al., *Online delivery of teaching and laboratory practices: continuity of university programmes during COVID-19 pandemic.* Education Sciences, 2020. **10**(10): p. 291.

[18] Ray, S. and S. Srivastava, *Virtualization of science education: a lesson from the COVID-19 pandemic.* Journal of Proteins and Proteomics, 2020. **11**(2): p. 77-80.

[19] De Jong, T., M.C. Linn, and Z.C. Zacharia, *Physical and virtual laboratories in science and engineering education.* Science, 2013. **340**(6130): p. 305-308.

[20] Erdosne Toth, E., B.L. Morrow, and L.R. Ludvico, *Designing blended inquiry learning in a laboratory context: A study of incorporating hands-on and virtual laboratories.* Innovative Higher Education, 2009. **33**(5): p. 333-344.

[21] Ford, D.N. and D.E. McCormack, *Effects of time scale focus on system understanding in decision support systems.* Simulation & Gaming, 2000. **31**(3): p. 309-330.

[22] McElhaney, K.W. and M.C. Linn, *Investigations of a complex, realistic task: Intentional, unsystematic, and exhaustive experimenters.* Journal of Research in Science Teaching, 2011. **48**(7): p. 745-770.

[23] Zacharia, Z.C. and C.P. Constantinou, *Comparing the influence of physical and virtual manipulatives in the context of the Physics by Inquiry curriculum: The case of undergraduate students' conceptual understanding of heat and temperature.* American Journal of Physics, 2008. **76**(4): p. 425-430.

[24] de la Torre, L., et al., *Providing collaborative support to virtual and remote laboratories.* IEEE transactions on learning technologies, 2013. **6**(4): p. 312-323.

[25] Hernández-de-Menéndez, M., A.V. Guevara, and R. Morales-Menendez, *Virtual reality laboratories: a review of experiences.* International Journal on Interactive Design and Manufacturing (IJIDeM), 2019. **13**(3): p. 947-966.

[26] Chu, E.T.-H. and C.-W. Fang, *CALEE: A computer-assisted learning system for embedded OS laboratory exercises.* Computers & Education, 2015. **84**: p. 36-48.

[27] Ekmekci, A. and O. Gulacar, *A Case Study for Comparing the Effectiveness of a Computer Simulation and a Hands-On Activity on Learning Electric Circuits.* Eurasia Journal of Mathematics, Science & Technology Education, 2015. **11**(4).

[28] Sell, R. and S. Seiler, *Improvements of multi-disciplinary engineering study by exploiting design-centric approach, supported by remote and virtual labs.* International Journal of Engineering Education, 2012. **28**(4): p. 759-766.

[29] Orduña, P., et al. *Classifying online laboratories: Reality, simulation, user perception and potential overlaps*. in *2016 13th International Conference on Remote Engineering and Virtual Instrumentation (REV)*. 2016. IEEE.

[30] Pastor, R., et al., *Renewable energy remote online laboratories in Jordan universities: Tools for training students in Jordan.* Renewable Energy, 2020. **149**: p. 749-759.

[31] Borrego, M., J.E. Froyd, and T.S. Hall, *Diffusion of engineering education innovations: A survey of awareness and adoption rates in US engineering departments.* Journal of Engineering Education, 2010. **99**(3): p. 185-207.

[32] Fichman, R.G. and C.F. Kemerer, *The illusory diffusion of innovation: An examination of assimilation gaps.* Information systems research, 1999. **10**(3): p. 255-275.

[33] Siddiqui, J.A. and R. Adams. *The challenge of change in engineering education: Is it the diffusion of innovations or transformative learning?* in *2013 ASEE Annual Conference & Exposition*. 2013.

[34] Lima, N., et al. *The VISIR+ project-helping contextualize math in an engineering course*. in *2017 4th Experiment@ International Conference (exp. at'17)*. 2017. IEEE.

[35] Wierer, J. and E.W. Chandler. *Analog and Digital Communications Laboratory Experiments Using Emona TIMS*. in *2011 ASEE Annual Conference & Exposition*. 2011.

[36] National-Instruments-Corporation. *Discover Electrocnics with Online SPICE Simulations*. 2022 04/16/2022]; Available from: https://www.multisim.com/.

[37] Richards, L., *Handling qualitative data: A practical guide*. 2020: Sage.