# WORKING WITH ELECTRONS: INTEGRATING "KITS" FOR HANDS-ON ONLINE LEARNING IN HOMES

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**ABSTRACT**
Teaching online can be a challenge, especially for courses which offer laboratory sessions. This research explores one method of replicating hands-on lab skills during an online course by developing a "Kit" which includes the necessary tools and components for students to complete the course labs at their homes. The intent is to provide an option for online courses, especially during unusual times, such as what occurred this semester during the closing of campus due to the COVID-19 situation. The study will share the approach, methods and components of the lab kit, as well as direct and indirect evidence of success of the research questions. The research focus is on how home lab Kits are effective for online learning to support lectures and reading; encourage self-efficacy; help students to become better researchers; create more meaningful project artifacts; keep students engaged in offline activities that are recurrent and periodic; and motivate students' dispositions to continue their efforts. Findings indicate that students do believe home Lab Kits are effective for supporting lectures and reading online; showed an increase of self efficacy when building circuits and interpreting results from their experiments; Kits are effective for helping them to become better researchers; projects created online were similar to projects created in a F2F setting; Kits kept them engaged in recurring offline activities; and Kits are effective for motivating them to continue their efforts.
**Keywords**: Online Teaching, Online Labs, Kits, Informal Learning, Hands-On Learning

## Introduction

Our university is a young private research university that has in total approximately 200 faculty members and 1,800 undergraduate students. The institution has a diverse international make-up of both faculty members (from more than 20 countries) and students (half from China and half from 70 other countries). The recent worldwide health challenges required all classes, including laboratories to migrate online quickly. Virtually all colleges and universities made the transition to conduct academic functions online amid the hazards of COVID-19 (Grush, 2020). Over the years, instructors have tried with varying degrees of success to provide students with valid laboratory experiences when learning in other setups than a traditional classroom (Jeschofnig & Jeschofnig, 2011). The belief was there was a critical need to create a hands on learning experience as close to (or better) than what had been offered to students in the past.

"Working with Electrons" is a project-based class which focuses on the discovery of electromagnetism. Along with lectures introducing major theoretical models that explain electromagnetic phenomena, students spend more than half of the class producing laboratory work, which includes assembling circuits, making self-oscillating inductive heaters, and other physical science concepts.

Seventeen students from eleven different locations around the world were enrolled in the online class. To ensure that the lectures and the experiments can be conducted with high quality through digital learning, the instructor designed the class including online sessions with at home interactive experiments using kits. Each student was asked to purchase basic kit equipment which included small electronics workbench with tools, instruments and materials to enable hands-on practice. Synchronous and asynchronous discussions were held via various digital platforms to guide students through the theories and the experiments.

  

The students met weekly using Zoom teleconference for synchronous interactions to discuss concepts and engage in group discussions. These sessions are recorded so that students who cannot attend can view later. In addition to synchronous interactions, the instructor also used Google Docs, Google Jamboard, and FlipGrid to facilitate asynchronous discussions among students. In Google Docs, questions are posted for each week and students are asked to provide responses connecting conceptual frameworks from each session so that everyone can view and comment on each other's thoughts. Google Jamboard is an interactive online whiteboard where students outline their thoughts and make annotations collaboratively. Students also post videos to present the originators of electromagnetic theory on FlipGrid.

Figure 1. *Student Visual Representations*


Figure 1 represents students' visual representation of the syllabus content. Students work in groups of different sizes, allowing them to collaborate with each other, so that they can foster connections that will allow them to work during the self-proposed projects for midterm and final together. The class uses Discord (https://discord.com), an online chat tool for groups similar to Slack, to improve the efficiency of multiple group communications and allow groups working simultaneously.

For the laboratory work, each student was provided with a multimeter, soldering station, prototyping tools and an assortment of components that allow them to work at their own rhythm. The concepts applied during the experiments are delivered with slides, notes and short video lectures recorded outdoors. To create a dynamic of team work where each participant is a stakeholder in the experiment, synchronous Question and Answer sessions are held separately for each group.

Every week, the students are asked to reflect on their learning experience and how they are able to connect the concepts among the theoretical readings, the practical knowledge delivered in the lectures and the experiments they complete. By the fourth week of a 14 week term, all students had run a one-on-one online video conference with the instructor to discuss their learning experience and how they are working remotely. On May 4, during week #11 of the term, the campus was reopened and six of the 16 students returned to F2F instruction.

The **Research Questions** for this study are focused on the introduction of Home Lab Kits for remote instruction and their effectiveness

1. Supporting lectures and reading;
2. Self-efficacy;
3. Helping the students to become better researchers;
4. Creating more meaningful project artifacts;
5. Keeping students engaged in offline activities that are recurrent and periodic (Self-regulated learning); and
6. Motivating students' dispositions to continue their efforts.

**Literature Review**

Transition to Online Learning due to COVID-19

In a volatile world, institutions of higher education that cannot determine how to work differently may not work at all (LeBlanc, 2020). Campuses that use a significant part of their funds as investment for resources such as hiring instructional designers have been able to manage the transition from face-to-face (F2F) to COVID-19 required remote teaching and learning (Kim, 2020). Campus IT support staff scurried to assist faculty from those who already have it covered to others who had been trying to ignore online opportunities for years (Grush, 2020). The move to online teaching has become a university collective and proactive endeavor to overcome the adverse situation due to COVID-19. The pandemic proved to be a catalyst of leading an infrastructure and technology upgrade that was put in place in a month or less rather than over a few years (Schaffhauser, 2020).

Online Labs and Lab Kits

Due to the vast shift to online teaching due to COVID-19, a question raised was about lab classes and if it is even possible to do so remotely while still meeting the learning objectives (Taft, 2020). Professors of courses that involve laboratory work have been trying to transition from hands-on labs to remote activities such as having students follow audiovisual guides of teaching assistants performing the experiments to complete their lab reports (Gross, 2020). In a F2F lab setting, monitoring student learning and providing feedback is reasonably straightforward. However, in an online lab setting, addressing the means to formative assessment is crucial. Formative assessments assist faculty to help students identify strengths and areas of improvement (Purkayastha, Surapaneni, Maity, Rajapuri & Gichoya, 2019).

Lab kits, if commercially designed or by faculty, can be a means to provide strong formative assessments. It should have the same standards applied from an on-campus setting to online labs. Unlike computer simulations, lab kits engage students physically in active learning. A well designed and equipped lab kit that is academically aligned to specific course learning outcomes can mirror the types of experiments students normally perform at on-campus labs (Jeschofnig & Jeschofnig, 2011). Using lab kits at home can be a good learning experience by having students share a photo of the experiment results to help verify that they performed the activity (Taft, 2020). Commercially assembled lab kits are an avenue to potentially meet the needs of science laboratory experience for online students. It provides engaging laboratory opportunities for online students while providing instructors more valuable time to interact with students (Jeschofnig & Jeschofnig, 2011).

Informal Learning and Hands-On

With the rules of organization in formal learning, there are shortcomings to keeping up with the development of new knowledge and informal learning serves to reduce the gap and complement through accessing contents that are somewhat inaccessible. Instructors have a responsibility with informal learning to bring the topic closer to students and ensuring the quality level. Although informal learning does not have directly defined rules, there should be a framework, pre-defined outcomes and tasks that will be followed (Konjalić, Jefić & Fodolović, 2018). With no instructor or lab assistant to set-up experiments, organize materials, clean up after, online students must take more responsibility for their own learning. Online students using lab kits to experiment independently tend to more seriously contemplate the laboratory experience (Jeschofnig & Jeschofnig, 2011).

**Methods**

This study was performed at a small private research university with a US/China partnership. The participants for this study were 17 second semester senior students (4 seniors, 11 sophomore, 1 freshman, and 1 junior), ten male and seven female students between the ages of 18-24 located in 11 different cities.

Procedure

The instructor attempted to provide a consistent method to create, deploy and integrate the lab kits in the course design. He secured additional lab fee funds from academic affairs; created a list of necessary materials, found the materials in various vendor websites, and placed the order through local and international suppliers. Specifically, the instructor created a document detailing how supplies were purchased by the students during the campus closure and shelter in place circumstances. He made sure the material and procedures aligned with the maturity level and capabilities of the students according to a pre-assessment form.

The syllabus was approved in the fall of 2018 with the general course structure of having offline classes with little to none online interactions. The scheduled time of the class was a weekly physical meeting of three hours, composed of 50% theory and discussion and other 50% of laboratory work. Given the situation of the virus outbreak COVID-19, the decision to move online the class brought also the challenge of running the experiments with remote instruction. The initial plan was to gather supplies that would facilitate installing in each of the homes of the students tools, instruments and supplies to perform the experiments that could help to have a similar learning experience to the one they would have had at the University's laboratory.

When it was close to the shipping date, the supplier reported difficulties given that their employees were also under strict quarantine. The instructor shared the challenges to have all the materials delivered and shared with the students a list of suggested materials with reference suppliers. The whole class collaborated to filter them and suggest replacements based on the location of the suppliers and the characteristics of the materials. The students contributed with alternative links that were quality was higher, shipping faster and had better customer service.

Having the students research and purchase their own materials brought a class dynamic where the students found themselves as collaborators and they worked with the materials more responsibly than when they worked at the laboratory on campus. For example, they were aware of the different models of instruments and tools, how complicated technical specifications could be for electronic components, etc. Not all aspects were improving the learning experience and one anecdote that is a good example is how students got capacitors from different suppliers that were of similar electrical characteristics but with different outlook, shape or color.

These differences added yet another obstacle when working remotely, by representing an obstacle for students who were not familiar with the components like capacitors and they asked for descriptions like “the orange round thing” when they actually had in their hands the right component but it was “the blue squarish thing”. These small complications somehow built into the course and the group could overcome them easily. But other issues brought challenges that some students saw as an obstacle. One example of this was when required to measure electrical parameters, some students had an instrument that did not measure frequency.

One of the initial observations from the experiences was that using the kits had great results with activities that can be clearly replicated by students (using a breadboard), because it helped to reinforce concepts understood from lectures and text readings. In some few cases, when the activity included some level of handcraft with manual skills, students showed a higher level of frustration with remote instruction (building a motor with a wire and a magnet) than in a face to face format.

Another tangible outcome is how the whole group’s vocabulary shifted towards a more mature terminology when they started having hands on activities with components. In the first activity the class did, they were asked to talk about the electromagnetic phenomena they experience in their daily life and the most abundant terms was “electricity” and after using components this term unfolded in terms like “electrical charge”, “magnetic field” and “radio waves”, showing a great development in the confidence they talk about the topic.

**Data Collection Instruments**
From the research questions **(**RQ), we have identified and aligned the following data collection instruments:

**RQ1.** Are the Home Lab Kits Effective Online for Supporting Lectures and Reading?

**Indirect Measure #A.** Day one Pre-Assessment with challenging (Results).

Table1.*Pre-Assessment Survey Questionnaire*

1. Maxwell equations are
    a. something I watched in a documentary
    b. something I used in other courses
    c. nothing I ever heard of
2. What is a multimeter used for?
    a. to measure many meters
    b. to measure resistance
    c. to measure current in [kA] and voltage in [nV to GV]
    d. to measure voltage in [mV to V] and current in [uA to A]
    e. some people use it to measure Qi energy and vitality
3. Can you solder?
    a. No and I don't want to try
    b. No but I want to try!
    c. Last time I grabbed a soldering iron, I smelled fried chicken
    d. I'm OK with cables but PCBs are more difficult
    e. SMT or PTH?
4. How familiar with a breadboard are you?
    a. I use it for having breakfast
    b. I used it in the course Interaction Lab
    c. I used many times and I know that the convention for ground is to use black color
    d. Yes, I can build a Tetris with NAND gates if you give me a schematic
    e. All of the above

**Indirect Measure #B.** Course Student Perception Data.
On April 13, 2020 students received a link to a Google Document which was made available to all students with the following information.

**"Student Perception of Online Class"**
Students, please read the items below carefully and share your honest feedback. Remember, please focus on the current online learning environment for this course, how you are learning and processing information. Your instructor is committed to assisting and providing the best support for your learning. The data you share will be anonymous and aggregated, so that your instructor will only receive your ideas.

**Most of the following questions are on the topic of the Home Lab Kits**
1. Please Share How the Home Lab Kits are Supporting the Online Lectures?
2. Please Share How the Home Lab Kits are Supporting the Online Readings?
3. Are the Home Lab Kits increasing your self-confidence for the topics learned? If so, please share how.
4. Are the Home Lab Kits helping you to become a better researcher? If so, please share how.
5. Do you believe the Home Lab Kits are helping you create more meaningful projects?
6. Do the Home Lab Kits help motivate you to continue your efforts?
7. What is one word that describes how you feel about the Home Lab Kits?
8. Overall, what is contributing to your learning in this online class?
9. What is one concrete action which the instructor can do now to improve online learning?"

**Direct Measure.** An analytical rubric was created to evaluate student projects. The rubric includes Concept Creativity; Concept Definition Clarity; Technique Subject Knowledge; Technique Research; Technique Feedback and Revision; Presentation Effort & Perseverance; Presentation Coherence; Presentation Outlook; Documentation References; Documentation Process; and Documentation Result Interpretation.

**RQ2.** Are Home Lab Kits Effective at Increasing Self-Efficacy Online?
**Indirect Measure.** Administered a subset on Motivated Strategies for Learning Questionnaire (MSLQ) (Pintrich & DeGroot, 1990; Pintrich, Smith, García & McKeachie, 1991; 1993) addressing Self-Efficacy.

Table 2.*Self-Efficacy Learning Questionnaire*

1. Compared with other students in this class I expect to do well.
2. I'm certain I can understand the ideas taught in this course.
3. I expect to do very well in this class.
4. Compared with others in this class, I think I'm a good student.
5. I am sure I can do an excellent job on the problems and tasks assigned for this class.
6. I think I will receive a good grade in this class.
7. My study skills are excellent compared with others in this class.
8. Compared with other students in this class I think I know a great deal about the subject.
9. I know that I will be able to learn the material for this class.

**RQ3.** Are Home Lab Kits Effective Online for Helping the students to become better researchers?
**Indirect Measure.** This data will be derived from the initial student perception survey on April 13, 2020, "Are the Home Lab Kits helping you to become a better researcher?"

**Direct Measure.** A comparison of 2018 student artifacts will be compared with the student artifacts generated this term using a rubric to measure research skills, and ability to integrate research questions.

**RQ4.** Are Home Lab Kits Effective Online for Creating more meaningful project artifacts?
**Indirect Measure.** This data will be derived from the initial student perception survey on April 13, 2020, "Do you believe the Home Lab Kits are helping you create more meaningful projects?"

**Direct Measure.** An analytical rubric was created to evaluate student projects. The rubric includes Concept Creativity; Concept Definition Clarity; Technique Subject Knowledge; Technique Research; Technique Feedback and Revision; Presentation Effort & Perseverance; Presentation Coherence; Presentation Outlook; Documentation References; Documentation Process; and Documentation Result Interpretation.

**RQ5.** Are Home Lab Kits Effective Online for Keeping students engaged in offline activities that are recurrent and periodic (Self-regulated learning)?

**Indirect Measure.** Administered a subset on Motivated Strategies for Learning Questionnaire (MSLQ) (Pintrich & DeGroot, 1990; Pintrich, Smith, García & McKeachie, 1991; 1993; Hargis, 2014; Hargis, 2000) addressing Self-Regulated Learning.

Table 3.*Self-Regulated Learning Questionnaire*

1. I ask myself questions to make sure I know the material I have been studying.
2. When work is hard I either give up or study only the easy parts.
3. I work on practice exercises and answer end of chapter questions even when I don't have to.
4. Even when study materials are dull and uninteresting, I keep working until I finish.
5. Before I begin studying I think about the things I will need to do to learn.
6. I often find that I have been reading for class but don't know what it is all about.
7. My study skills are excellent compared with others in this class.
8. When I'm reading I stop once in a while and go over what I have read.
9. I work hard to get a good grade even when I don't like the class.

**RQ6.** Are Home Lab Kits Effective Online for Motivating students' dispositions to continue their efforts?
**Indirect Measure.** This data will be derived from the weekly surveys where the instructor asks students, "How do you feel?" on a scale from 1 to 5.

**Direct Measure.** Instructor documentation on how he perceives students are feeling and direct conversations documented on students sharing their feelings, and stories of anxiety, and stress.

**Results**
**Instrument #1.** Weekly surveys where the instructor asks students, "How do you feel?"

Table 4.*Quantitative data from survey question, "How do you feel?"*

| Week | Standard Deviation | Mean |
|---|---|---|
| 1 | 0.636 | 3.82 |
| 2 | 0.600 | 4.12 |
| 3 | 0.772 | 4.06 |
| 4 | 0.655 | 4.00 |
| 5 | 0.786 | 4.29 |
| 6 | 0.726 | 4.35 |
| 7 | 0.650 | 4.59 |
| 8 | no data | no data |
| 9 | no data | no data |
| 10 | 0.873 | 3.71 |
| 11 | 0.799 | 3.82 |
| 12 | 0.775 | 4.20 |

**Instrument #2.** Course Student Perception Data (the number in the parenthesis is the number of students who agreed with this comment). (Appendix A)

**Instrument #3.** An analytical rubric was created to evaluate student projects. The rubric includes Concept Creativity; Concept Definition Clarity; Technique Subject Knowledge; Technique Research; Technique Feedback and Revision; Presentation Effort and Perseverance; Presentation Coherence; Presentation Outlook; Documentation References; Documentation Process; and Documentation Result Interpretation. This rubric will measure attributes of deep learning, meaningfulness, connection to concepts, alignment to learning outcomes.

Table 5.*Summary for Midterm Projects Mean Values [categorized through the pre-assessment scores]*

| Student Scores in Three Categories (n) | Concept: Creativity | Concept: Definition | Technique: Knowledge | Technique: Revision |
|---|---|---|---|---|
| Low (5) | 2.72 | 2.52 | 2.58 | 2.68 |
| Middle (5) | 2.68 | 2.74 | 2.80 | 2.64 |
| Top (6) | 2.68 | 2.67 | 2.65 | 2.62 |

Notes: Student pre-assessment scores were divided into three categories (Bottom group between 0-4; Middle group between 5-6; Top group between 7-9).

Table 6.*Summary for Final Projects [categorized through the pre-assessment scores]*

| Student Scores in Three Categories (n) | Concept: Creativity | Concept: Definition | Technique: Knowledge | Technique: Revision |
|---|---|---|---|---|
| Low (5) | 2.50 | 2.63 | 2.30 | 2.30 |
| Middle (5) | 2.58 | 2.59 | 2.63 | 2.24 |
| Top (6) | 2.59 | 2.60 | 2.42 | 2.31 |

Notes: Student pre-assessment scores were divided into three categories (Bottom group between 0-4; Middle group between 5-6; Top group between 7-9)

Table 7.*Summary for Overall Evaluation Midterm Project Presentations [categorized through the pre-assessment scores]*

| Student Scores in Three Categories (n) | Effort | Coherence | Outlook |
|---|---|---|---|
| Low (5) | 2.82 | 2.68 | 2.66 |
| Middle (5) | 2.78 | 2.74 | 2.64 |
| Top (6) | 2.73 | 2.65 | 2.68 |

Notes: Student pre-assessment scores were divided into three categories (Bottom group between 0-4; Middle group between 5-6; Top group between 7-9)

Table 8.*Summary for Overall Evaluation Final Project Presentations [categorized through the pre-assessment scores]*

| Student Scores in Three Categories (n) | Effort | Coherence | Outlook |
|---|---|---|---|
| Low (5) | 2.63 | 2.63 | 2.43 |
| Middle (5) | 2.72 | 2.49 | 2.73 |
| Top (6) | 2.81 | 2.57 | 2.59 |

Notes: Student pre-assessment scores were divided into three categories (Bottom group between 0-4; Middle group between 5-6; Top group between 7-9)

**Instrument #4.** Motivated Strategies for Learning Questionnaire (MSLQ) for Self-Efficacy and Self-Regulated Questionnaires, specified on Table 2 and on Table 3.

  

Table 9.*Summary for Self Efficacy Data (collected week #10 and #14)*

| **Item** | **Low (5) Week 10 Week 14** | **Middle (5) Week 10 Week 14** | **Top (6) Week 10 Week 14** |
|---|---|---|---|
| Compared with others in this class I expect to do well. | 1.50 | 1.83 | 1.80 |
| | 1.00 | 2.00 | 1.60 |
| I'm certain I can understand the ideas taught in this course. | 1.25 | 1.50 | 1.40 |
| | 1.50 | 2.00 | 1.60 |
| I expect to do very well in this class. | 1.00 | 1.50 | 1.80 |
| | 1.25 | 1.83 | 1.60 |
| Compared with others, I think I'm a good student. | 0.75 | 1.83 | 1.40 |
| | 1.25 | 2.00 | 1.80 |
| I am sure I can do an excellent job on the tasks assigned. | 1.00 | 1.67 | 1.60 |
| | 1.25 | 1.83 | 1.60 |
| I think I will receive a good grade in this class. | 1.00 | 1.67 | 1.60 |
| | 1.50 | 2.00 | 1.60 |
| My study skills are excellent compared with others. | 0.50 | 1.33 | 1.20 |
| | 0.50 | 1.83 | 1.40 |
| Compared with others, I think I know a great deal about the subject. | 0.50 | 1.50 | 1.20 |
| | 0.50 | 1.67 | 1.40 |
| I know that I will be able to learn the material for this class. | 1.25 | 1.67 | 1.60 |
| | 1.75 | 2.00 | 1.80 |

Notes: Student pre-assessment scores were divided into three categories (Bottom group between 0-4; Middle group between 5-6; Top group between 7-9)

Table 10.*Summary for Self Regulated Learning Data (collected week #10 and #14)*

| **Item** | **Low (5) Week 10 Week 14** | **Middle (5) Week 10 Week 14** | **Top (6) Week 10 Week 14** |
|---|---|---|---|
| I ask myself questions to make sure I know the material I have been studying. | 1.75 | 1.83 | 1.2 |
| | 1.5 | 2.00 | 1.4 |
| When work is hard I either give up or study only the easy parts. | 0.5 | 0.17 | 0.2 |
| | 0.75 | 0.67 | 0.6 |
| I work on practice exercises and answer end of chapter questions even when I don't have to. | 0.75 | 1.0 | 1.2 |
| | 0.5 | 1.83 | 1.2 |
| Even when study materials are dull and uninteresting, I keep working until I finish. | 1.75 | 1.67 | 1.8 |
| | 1.75 | 1.83 | 1.8 |
| Before I begin studying I think about the things I will need to do to learn. | 1.5 | 1.83 | 1.6 |
| | 1.5 | 1.67 | 1.8 |
| I often find that I have been reading for class but don't know what it is all about. | 1.25 | 1.0 | 0.8 |
| | 1.0 | 1.50 | 0.6 |
| My study skills are excellent compared with others. | 1.25 | 1.0 | 1.0 |
| | 0.75 | 1.67 | 1.2 |
| When I'm reading I stop once in a while and go over what I have read. | 1.5 | 1.5 | 1.2 |
| | 1.75 | 1.50 | 1.0 |
| I work hard to get a good grade even when I don't like the class. | 0.75 | 1.33 | 1.2 |
| | 0.75 | 1.17 | 1.2 |

Notes: Student pre-assessment scores were divided into three categories (Bottom group between 0-4; Middle group between 5-6; Top group between 7-9)

Table 11.
*Comparison of Content Pre/Post-Assessment (Results) Averages*

| **Pre/Post Assessment Items** | **Pre (% in Common)** | **Post (% in Common)** |
|---|---|---|
| 1. Maxwell equations | 43.1 | 100 |
| 2. Using a multimeter | 60.3 | 57.1 |
| 3. Familiarity with soldering | 56.8 | 88.1 |
| 4. Familiarity with a solderless breadboard | 23.5 | 71.1 |

  

**Discussion**

The following narrative connects the data collected to each Research Question (RQ). Are Home Lab Kits Effective Online for:

1. Supporting lectures and reading.
2. Self-efficacy.
3. Helping the students to become better researchers.
4. Creating more meaningful project artifacts.
5. Keeping students engaged in offline activities that are recurrent and periodic (Self-regulated learning)
6. Motivating students' dispositions to continue their efforts.

The data supports that students do believe that the home Lab Kits are effective for supporting lectures and reading online. Students commented in the Course Student Perception (see Appendix) "Kits help me better understand the theories learned during class by allowing hands on learning; give us actual experience in operating soldering, building circuits, etc; include most of the materials we need for class; Were a great help, allowing me to do a lot of real-world experiments, thus discovering more details of digital circuits that any simulations couldn't show; and helps me understand more about the concepts mentioned in class."

Lectures along the course included theoretical explanations, historical context of the discoveries of different phenomena and practical applications. Readings, videos and audio recordings were also contributing to have different perspectives and help to analyze and utilize the different tools to work through projects. From the instructors' perspective, the results when using the kits at home were at least as effective as student work accomplished in a F2F studio doing physical laboratory work. And their explanation was that lectures and readings put students in a listening mode, as the Home Lab Kits were more effective at bringing real scenarios where those high level concepts needed to be applied.

An unexpected finding was the depth that students could relate theory to the self-directed exercises with the kits. Originally, the main focus when designing the kits was to limit the type of experiments, based on the idea that students would not have physical contact with laboratory instruments. This shifted very quickly when the kits started being used and the students expressed high expectations about the complexity of the projects they could build, even though some had a degree of frustration when they needed to debug the circuits themselves.

The working methodology with the kits was using the online platform "Discord" in small groups of two or three students about the progress, each participant building circuits, aiming at lowering the frustration levels, clarifying the instructions about the objectives to obtain from the exercise, being able to relate the topics of the class and how to explain what they were experiencing in real life. While the summary of Self Efficacy (Table 6) doesn't show a significant difference in the experience of the students, some teams reported that they were able to understand the underlying theory despite having difficulties building the circuits and experiments. Their main reason they reported was the contact with the physical material (Appendix)

Students were asked to use a simulator and to calculate parameters in order to contrast the results. Later in the semester, they were asked to analyze a circuit and to assemble and test it. There was a substantial contrast in their engagement (Table 1); the depth they researched about peripheral topics; and the amount of hours they spent working on it. The instructor's interpretation of this was that instead of finding the "right" answer, they spent their time investigating, exploring and deriving deeper questions. This result further attended to students' perception of their own abilities.

For the second research question, students showed an increase of self efficacy (Table 6) when building circuits and interpreting results from their experiments. The first sessions and online one-on-one consultations were all reporting anxiety about whether they would be able to finish their circuits or if they could solve problems alone. Through the different activities several teams expressed confidence and were able to combine circuits to understand how they work.

This finding is also reflected by the pre and post assessments (Table 8) responses on how comfortable they would approach building circuits when answering questions regarding physical tools such as soldering and connecting circuits in a breadboard. This positive student perspective supported their further beliefs on how the Kits could enhance their questioning skills.

The focus of the third research question found that one hundred percent of the students responded affirmatively (Appendix) to the Kits are Effective Online for helping them to become better researchers. Students detailed their perceptions of improved research with comments such as "by taking a careful look at the mechanisms behind the components, I developed a deeper understanding of some important science theories; without reading the corresponding data sheet and analyzing all of the pins, I can not finish my project; and when the program does not work with the circuit, it propels me to do research about it to find out where it was not done correctly and enables me to get to know about the related knowledge more effectively."

The fourth part of this study found that when comparing the 2018 editions of the same course (Cossovich, 2020), where studio work and F2F classes were offered to support projects, the projects created online using Home Kits did not have any appreciable difference from F2F projects. In Project Based Learning courses, it is common to discuss among faculty about the "cookie cutters" when referring to how much freedom to give students but also how students can create a quality project that can be designed, developed and presented in a short period of time. This term can also be used in a negative sense, where students will not have the chance to create, explore and make mistakes with such a strict level of guidance from the instructors. When we introduced the idea of having remote instruction and students using kits, the question of whether we would be able to let them create their own projects, and have agency over their results or we need to use a "cookie cutter" was raised. Overall, the instructor found a satisfactory dynamic between an open-ended and "cookie cutter" experience, which resulted in students engaging in meaningful discussions and demonstrating a great diversity of projects (Tables 2 and 3) during their presentations. It appeared that students were able to balance the openness with quality and time, which are key attributes for online learning.

Our fifth question addressed a major challenge for learning online, the concept of self-regulated learning. Our results (Table 7) showed that students believe that the Kits kept them engaged in recurring offline activities, supported by their statements, "I can dig deeper into my interests; besides the projects I need to do, I can also try some interesting circuits, such as light control; there are always some ways to improve the circuit with these components; I will continue discovering the feasible ways to improve the project; and with the advice of my professor, I am curious to explore the potential of all the material in my Kits." This data also seems to keep students' attitude and desire to make progress, which was especially important during less than ideal health challenges around the world.

The sixth research item was to ascertain if the Kits could assist with student motivation, which was especially key, in the absence of traditional F2F motivators. Students recognize (Appendix) that the Kits are effective online for motivation and enhancing their dispositions to continue their efforts, which was supported as they use adjectives to describe their feelings about the Kits as "Fantastic, Inspiring, Useful, Fascinating, Exciting, Challenging, and Useful." Students responding with positive dispositions help them connect to their intrinsic motivation, that helped them persevere during times of feeling alone. This was also showed in the project they showed during Midterms and Finals (Tables 4 & 5)

In addition, through reviewing the student data, we arose at several additional inquiries worth discussing.

- How does this online, at Home Kit approach compare to F2F?
    - Key differences between the two approaches include a technical aspect given that some activities and exercises were not possible to carry because they require more complex tools (such as oscilloscopes, regulated power supplies, frequency generator, etc) or materials (equipment to manipulate high voltage, high power disipators, PCB milling CNC, etc).
    - Students suggested several advantages, which included the ability to have their own electronic workbench at home and work in flexible times when compared to the laboratory work at the studio.

- Could the Kits be part of an ongoing regular lab offered online?
    - The instructor expects to teach this course in an online format simultaneously with an offline version, both groups of students working with the same Kits. The COVID-19 emergency actually informed the instructor about different ways the experiments could be designed to be carried out by the students independently. The expectations of using the kits both for online and offline activities are that it could be possible to allocate more resources to share the finding of the experiments, discuss possible implementations and give space to answer questions from the students. Instead of the traditional setup where the instructor spends a significant portion of the allocated time for laboratory work giving instructions and supervising closely how to carry out the activities, this time could be used to reflect on the learning.

The quality of the student artifact was higher overall (accounting [not controlling] student prior knowledge, data collected and observed indicates that this a typical class with respect to GPA, background, experience, etc.). We believe this has happened for the following reasons:

1. The class was one of the few opportunities during the semester for the students to carry on their own project, pursuing their interests in the Project Based Learning modality. Other classes were proctoring exams remotely or assigning extra writing exercises to complement the lact of face to face activities.
2. The challenge of being part of developing a new teaching methodology together with the instructor for a course that was integrating disciplines was a motivation factor for students to work longer and research more.
3. The Kits gave a sense of agency and ownership over the way they approached practicing when compared to utilizing materials already existent in the studio inventory of the University.
4. The activities in class required students to collaborate between each other in rotating groups as well as to work with partners, giving a sense of community belonging and accountability in front of the other participants.

Based on the class's experience, the instructor has observed that the lack of integration between different communication tools was far from ideal. For example, when he started using Discord learning management system for a planned asynchronous task for groups of three students, they could not talk among each other unless they were already "friends" with each other. That single technological inability was a distraction from the class. Even simple tasks for a F2F class session like using a soldering iron or measuring current have become technical challenges that need very careful planning.

However, the instructor believes this will not be a hindrance for online learning and remote communications. Every week, students are surveyed about their class experience and suggestions. Some of them have been volunteering to help on the technical challenges the class faces, creating a real learning community. Thanks to students' recommendations, the instructor is made real time, continual adjustments and improving the class by trying new technology and pedagogy to make the online sessions more engaging.

Limitations of Study

The variables for this study are numerous due to the rapid migration of courses online; the students physical location; and subsequent wide differences in internet connections and several of the students (n=3) reported during office hours that the overload work they had given the circumstances was influencing their lack of attention and difficulties to concentrate in class. As an example, two of them reported sleeping less than five hours average during the midterm exam week. Great influence of last week mixed mode tryout (n=6) was reported in the last class feedback form, where several of the remote students (n=5) mentioned that remote learning did not work well for them, while for them as in other weeks. The situation of having students in the classroom with physical manipulatives and others simultaneously having online instruction proved to be another challenge in the last two weeks of classes.

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**Appendix.** Course Student Perception Data

1. **Please Share How the Home Lab Kits are Supporting the Online Lectures**?

- The Kits help me better understand the theories learned during class by allowing hands on learning.
- The Kits we have at home give us actual experience in operating soldering, building circuits, etc.
- The Kits are really helpful. But it is a little hard to figure it out by ourselves at home.
- The Kits include most of the materials we need for class. Great help!
- Practice makes perfect. The Kit allowed me to do a lot of real-world experiments, thus discovering more details of digital circuits that any simulations couldn't show.
- The Kit definitely helps me understand the theoretical concept we have learnt during the class time.
- The Kit is very useful and provides many materials needed with clear information.
- The Kit helps me understand more about the concepts mentioned in class.
- While it is certainly helpful and seems robust, it is hard to understand what every function does when I lack the knowledge in the real world as well (new to the subject.

2. **Please Share How the Home Lab Kits are Supporting the Online Readings**?

- The Kits and the readings are two distinct factors supporting my online learning. (3)
- The Kits allow us to turn the theory in the readings to an actual project or a little gadget in real life.
- The Kits provide a kind of practical application of the Online Readings.
- The Kits enable me to know the information in the readings in a more concrete way.
- The Kits allow me to build real stuff based on the theory in the readings.

3. **Are the Home Lab Kits increasing your self-confidence for the topics learned? If so, please share how**.

- Yes (6)
- Yes. By getting my hands dirty, I could have a better understanding of the theories learned in class.
- I think seeing my own circuit works definitely increases my confidence in the electric knowledge that I learned.
- Of course, yes. It is even not possible to learn without the help of experiments.
- Yes! Getting a hand on the Kit components makes me feel confident about building any circuit.
- I'd like to say no and yes. No. Because I used to believe that the digital circuit is entirely discrete and easy to design. However, after I conducted many experiments using the Kit, I realized that there are lots of analog factors I should consider when creating a digital circuit. Yes. Because after using the Kit, I learned way more about the digital circuit, and now I'm more confident about what I've learned.
- Of course. When I complete the construction of my own circuit and see it can successfully run, I definitely get a sense of achievement.

  

- Yes. Being able to make the digital circuit into a real one helps to learn more about the circuit knowledge and bring attention to many details that are hard to notice through digital simulations.
- Yes. I am able to explore all the related stuff by myself and play with it.

4. **Are the Home Lab Kits helping you to become a better researcher? If so, please share how**.
- Yes (6)
- Yes, by taking a careful look at the mechanisms behind the components, I developed a deeper understanding of some important science theories.
- Yes, by delving more into all the details and unexpected problems.
- Yes. For example, as for the NE555 and the 9013 transistors, without reading the corresponding data sheet and analyzing all of the pins, I can not finish my project.
- Yes. When something goes wrong or do nor work with the circuit, it propels me to do research about it to find out where it was not done correctly and enables me to get to know about the related knowledge more effectively.
- Yes. With the raw material, I can explore more than what the professor asks and do my own modifications.

5. **Do you believe the Home Lab Kits are helping you create more meaningful projects**?
- Yes (6)
- Yes.It is giving me flexibility in what to build.
- The kits give me more options when building projects, and I can buy the parts I need online to make my project finished.
- Yes, it provides many possibilities for us to discover what we can make out of the materials at hand.
- Yes, using the kit we create something in real-world.
- Yes, it provides me the basic support to discover the world of electronic circuits.
- Yes, the kits bring certain inspiring possibilities.
- Yes, it provides me with more possibilities when designing my own project.

6. **Do the Home Lab Kits help motivate you to continue your efforts**?
- Yes (4)
- Yes. I can dig deeper into my interests.
- Yes. Besides the projects I need to do, I can also try some interesting circuits, such as light control.
- Yes, there are always some ways to improve the circuit with these components.
- Just so-so.
- Yes, with the help of the Kit, I will continue discovering the feasible ways to improve the project.
- It depends? Sometimes after too many failed attempts, it gets a bit tiring and overwhelming.
- Yes. With the advice of my professor, I am curious to explore the potential of all the material in my Kits.

7. **What is one word that describes how you feel about the Home Lab Kits**?
- Fantastic
- A little **tricky** but generally **fine**
- Inspiring
- Useful, but the quality really needs some improvement
- Fascinating
- Exciting but sometimes also challenging
- Challenging
- Useful

8. **Overall, what is contributing to your learning in this online class**?
- My interaction with professor and fellow after class.
- Building interesting projects with my classmates.
- Group discussion.
- Self-learning.
- The anti-pressure ability.
- Certain extent of self exploration.
- Self-learning and discussion with classmates and professor.

  

9. **What is one concrete action which the instructor can do now to improve online learning?**

- I think learning online is harder than learning in face to face. Hope professor can adjust the grading policy. (2)
- I think it is hard to say immediate actions right now, but I definitely think the learning process is building itself step by step.
- Being more specific on the overall requirements and what is expected from our work.
- Holding more office hours to improve the interaction procedure.
- Explaining some theories and requirements as well as guidelines more clearly.
- Have more breaks.