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Studying the Experience of Electrical and Computer Engineering Students in a Face-to-Face Electronics Laboratory Course during COVID-19 Pandemic

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Studying the Experience of Electrical and Computer Engineering Students enrolled in an improvised Face-to-Face Electronics Laboratory Course offered during the COVID-19 Pandemic.

Abstract

Circuits and electronics laboratory courses have traditionally been offered in a face-to-face format in a physical lab setting with instruments such as power supplies, function generators, digital multimeters, and oscilloscopes, among others. However, this COVID-19 pandemic has forced universities all over the world to adopt newer strategies in implementation of traditional face-to-face laboratories. This sudden change in the format of traditional face-to-face laboratories means that there is a pressing need for thoughtful planning of laboratory education to minimize the negative effects of this pandemic. While significant literature exists detailing both the advantages and the disadvantages of non-traditional electrical engineering laboratory courses implemented through either standalone or some combination of simulations, remote control of laboratory equipment, and/or distant labs implemented through at-home lab-kits; I did not find any relevant literature on improvisation of face-to-face laboratory courses for efficient instruction during a pandemic. This paper describes the implementation of one such improvised face-to-face laboratory course offered during the COVID-19 pandemic. The paper also studies the experience of students enrolled in this improvised face-to-face laboratory course. The feedback is collected from the students in the form of surveys. The surveys address questions on ease of procuring the lab-kit, working alone on a bench vs. working in a group, anxiety of being in a laboratory space during the COVID-19 pandemic, and working on lab reports in a virtual team, among others. The survey results show that the students' confidence grew per week as they worked alone in this improvised face-to-face laboratory setting during the pandemic. However, the survey results also show that the students struggled to effectively collaborate with their lab group members in the writing of their lab reports. Therefore, the paper also offers some solutions that may aid students in effective collaboration with their group members in the writing of their lab reports. The structure of this improvised face-to-face laboratory setting and suggested solutions to improve collaboration among students may help other educators with a more robust planning and implementation of their improvised face-to-face laboratory courses during this COVID-19 pandemic and beyond.

Introduction

The spread of COVID-19 became a global concern at the start of the year 2020[1-3]. On January 26, 2020, the Centers for Disease Control and Prevention (CDC) confirmed the first case in California[4-8]. In fact, ten of the first twenty confirmed COVID-19 cases in the United States occurred in California[9]. California Governor Gavin Newsom declared a State of Emergency on March 4' 2020[10, 11]. On March 17'2020 all California State University (CSU) campuses began immediate transition to virtual mode of instruction to better implement the mass gathering guidelines established by the California Department of Health. California Polytechnic State University (Cal Poly) located in San Luis Obispo also transitioned to virtual mode of instruction and all classes in the College of Engineering within the university were offered virtually in the Spring 2020 quarter. While it is comparatively easier to transition lecture-based courses to online instruction, the transition of laboratory courses to virtual instruction requires significant more thought and planning[12, 13]. Thankfully, there is plenty of literature available on various forms of non-traditional implementation of laboratory-based courses. Non-traditional laboratories are commonly classified into three categories[14, 15]:

Online laboratories: These typically include simulation-based exercises that can be implemented through software-based platforms such as - PSPICE, LTspice, Matlab, LabVIEW, Java scripts etc. [16].

Remote laboratories: These typically include remote-control of laboratory equipment usually located in a university setting. These remote laboratories are very commonly implemented using LabVIEW. In the past decade National Instruments has also developed multiple technologies that also allow students to remotely control the laboratory equipment located in university settings[17, 18].

Distant laboratories: These typically include hands-on exercises implemented through some form of portable at-home lab-kits. Regarding circuits and electronics laboratory courses, such portable laboratory setups commonly consist of devices such as Arduino, Analog Discovery, and general-purpose digital multimeters and oscilloscopes that can be purchased for under $50 from vendors such as Amazon[19-21].

While novel work on implementation of non-traditional labs continues to be published, several of the commonly identified issues with non-traditional labs remain[14, 15, 22-27]:

1. Not all students live in areas with access to the internet.
2. Not all students can afford to pay for the internet.
3. The internet connection if available may be unreliable.
4. Obtaining licenses for simulation platforms may not be economically viable.
5. Regarding remote labs, students may need extensive training in remote access and control of laboratory equipment.
6. Regarding remote labs, students typically do not prepare experimental setups; they only access and control the setups prepared by the instructor. This may lead to underdeveloped procedural skills.
7. Regarding remote labs, typically only one student can control the equipment at any given time. This may require setting up of multiple experimental setups which may not be viable because of lack of resources and/or time.
8. Regarding distant labs, not all students can afford to pay for the lab-kits.
9. Regarding distant labs, more advanced experiments may be difficult to implement with less sophisticated at-home lab-kits.
10. Lack of teamwork and collaboration.
11. Lack of hands-on experience with real-world sophisticated lab equipment.
12. Non-traditional labs may result in reduced contact time between student and instructor.
13. Remote access of university-owned laboratory computers may increase security concerns.

Even though non-traditional laboratories have their shortcomings, they also offer some important advantages, the most common and important advantage being their flexibility of schedule for adult learners with multiple responsibilities. While non-traditional labs are slowly gaining popularity, most engineering students still prefer traditional hands-on laboratory activities and see it as a critical part of their engineering education. In a recent study done during this COVID-

19 pandemic by Evstatiev and Hristova 58% of electrical engineering students showed interest in traditional face-to-face labs, 26% had no preference, and only 16% showed interest in virtual labs[28]. Engineering is a highly practical discipline and traditional hands-on laboratories allow students to build, experiment, test, and observe scientific phenomena in a collaborative environment. While it is true that distant labs allow students hands-on experience with circuit design and measurements using portable lab-kits, they usually only prove useful for introductory DC circuits laboratory courses. Advanced experiments that require for example, measuring phase-shifts between sinusoidal signals, obtaining Lissajous patterns, obtaining IV characteristics of semiconductor device components using XY mode of the oscilloscope etc. cannot be performed effectively with inexpensive general purpose at-home portable lab-kits.

Cal Poly's College of Engineering collected data from its students assessing their interest in enrolling in traditional face-to-face laboratory courses. In response to the significant interest from students in enrolling in traditional face-to-face laboratory courses, the College of Engineering started offering around 10% of its laboratory-based courses in traditional face-to-face format beginning Fall 2020 quarter [29]. These traditional face-to-face laboratory courses were implemented strictly following the California State University (CSU) system and the County of San Luis Obispo Public Health Department guidelines [30, 31]. The faculty were given the choice to teach the laboratory courses in both the traditional face-to-face format and the non-traditional virtual format. None of the faculty were forced to teach the traditional face-to-face laboratory sessions. This allowed faculty over the age of 60 and those with pre-existing conditions to opt out of teaching traditional face-to-face laboratory sessions. The EE 346 – Semiconductor Device Electronics Laboratory was one such course offered in the Winter 2021 quarter in a traditional face-to-face format. A total of four sections of EE 346 were offered in the Winter 2021 quarter, one section was traditional face-to-face section while three sections were non-traditional virtual sections. The students were given the choice to register for either the traditional face-to-face laboratory course or the non-traditional virtual laboratory course. This allowed the students with pre-existing conditions to opt out of the traditional face-to-face laboratory course. The maximum enrollment capacity for the traditional face-to-face section was set to 18 students by the Electrical Engineering Department based on the availability of lab space and COVID-19 guidelines set by the CSU and the County of San Luis Obispo Public Health Department. A total of 18 students (a mix of electrical engineering and computer engineering majors) were initially enrolled in the course. One student withdrew from the course in week-2 citing medical reasons not related to COVID-19. This student also did not enroll in the alternative non-traditional virtual lab sections that were running concurrently with the traditional face-to-face section. While more students were interested in enrolling in the traditional face-to-face section, they chose not to primarily citing financial reasons, most of these students lived out of town and did not want to accrue additional living expenses while taking only a few in-person courses on campus.

Description of EE 346 – An Introductory Electronics Laboratory Course

EE 346 is a required 1-unit core-course for both electrical and computer engineering students at Cal Poly. It is an introductory electronics laboratory course that consists of eight lab experiments to be completed in a period of 10-weeks. Only one laboratory experiment was scheduled per week. The general purpose of these laboratory experiments is to introduce students to the device characteristics of semiconductor device components. The titles of the eight laboratory experiments are:

1. Introduction to PSpice
2. Operational Amplifiers
3. Diode Characteristics
4. Diode Circuits
5. Breakdown Diodes
6. JFET Characteristics
7. Bipolar Junction Transistor
8. Design of a Common-Emitter Biasing Circuit

The instruments used to perform these hands-on laboratory experiments include:

1. Agilent DC Power Supply – Model E3640A
2. Rigol Programmable DC Power Supply – Model DP832
3. Hewlett Packard Function Generator – Model 33120A
4. Agilent Digital Multimeter – Model 34401A
5. Keithley Source-Meter – Model 2400
6. Keysight InfiniiVision Oscillocope – Model MSO-X 2022A

These eight laboratory experiments along with their associated prelab accounted for 90% of the lab course grade while a separate lab final exam accounted for the remaining 10% of the lab course grade.

Structure of the Improvised EE 346 Face-to-Face Laboratory Setup

Approximately three weeks before the start of the Winter 2021 quarter, all students of the traditional face-to-face lab section were sent an email with links to digikey.com and mouser.com shopping carts to allow them to purchase their own individual lab kits. The email also included link to the university store to allow them to purchase the required lab manual. The lab-kit consisted of several resistors and capacitors, six 1N4001 rectifier diodes, two 1N4735 breakdown diodes, two red LEDs of any model, one J113 JFET, and two 2N2222 BJTs. The cost of the lab-kit (not including shipping charges) was less than $15 at the time. All students except one had received their lab-kits before the start of the first face-to-face lab experiment. The instructor provided that student with their own lab kit to allow them to perform the lab experiments scheduled for that week. This student came to the lab with their own lab kit the following week.

The laboratory experiments were carried out in two rooms of dimension 27.5’× 29’ each. Each room consisted of nine separate lab benches that were positioned at least 6 ft apart. The following social-distancing and disinfection plan was put in place by the Electrical Engineering Department in accordance with CSU and the County of San Luis Obispo Public Health Department guidelines to protect the students and the instructor:

1. All students will present their Green Pass to the instructor before entering the lab room.
2. All students and the instructor will wear a face covering at all times.

3. All students and the instructor will wear a face-shield in addition to the face-covering if the distance between them reduces to less than 6 ft for more than 2 minutes.
4. Upon entry into the room, students will use the provided hand sanitizer.
5. Students will next disinfect the desk surface of their assigned workstation with provided disinfectant spray or wipes. Students will disinfect any tools or equipment that is to be used by that individual.
6. Ensure proper ventilation while using disinfectants.
7. To protect students, faculty, and staff and to ensure that the products are used effectively, instruction on how to apply the disinfectants according to the label is recommended.
8. All students will watch the laboratory introduction video made available on YouTube before starting the lab. Students will bring their own headphones to listen to the video.
9. After finishing lab, the student will repeat the process of disinfecting the desk surface and tools or equipment.
10. Students will use the provided hand sanitizer as they leave the lab.

The university provided on-campus testing facilities for both asymptomatic and symptomatic students. To access the laboratory space throughout the quarter, students were required to complete a daily screening via the COVID-19 Daily Self-Screening Tool that could be accessed via the university portal or daily email/text. Once a student had completed their daily screening, they would receive a daily campus pass that would allow them to enter the laboratory space after inspection.

PASS TYPES	GREEN PASS (CERTIFIED)	BLUE PASS (NOT TESTED)	YELLOW PASS (LIMITED)	RED PASS (NOT CERTIFIED)	NO PASS (NOT CERTIFIED)
Student Status	• No self-reported symptoms • Submitted a test within 3 days	• No self-reported symptoms • **Not submitted a test within past 3 days**	• University hold (OSRR) • Q/QIP (potential exposure)	• Self-reported symptoms • On-campus resident under care of IQST	• Has not completed the Daily Health Screening and therefore a pass has not been generated
Campus Access	Cleared to access campus facilities (no restrictions)	Limited access to campus facilities (only to testing sites) Enforcement begins 3/29	Limited access to campus facilities (health and safety)	No access to campus facilities (health and safety)	No access to campus facilities (health and safety)

Figure 1. Format of the Daily Campus Pass (https://coronavirus.calpoly.edu/covid-19-self-screening)

The students were required to have no COVID-19 symptoms and a negative test result submitted within three days to receive a Green Pass. The instructor inspected every student's pass for every single laboratory session and only allowed those students into the lab space that had a Green Pass for the day. None of the students informed the instructor of a positive test result for COVID-19 during the quarter. In any event, students were not compelled to come to the laboratory space if it made them uncomfortable at any time or for any reason. A non-traditional virtual laboratory session was made available for those students that felt uncomfortable coming to the laboratory.

One student chose to take virtual laboratory sessions after completing three traditional face-to-face laboratory sessions for personal reasons. Another student chose to self-quarantine after performing six traditional face-to-face laboratory sessions because their roommate's girlfriend had tested positive for COVID-19. Again, it is important to note that only one laboratory experiment was scheduled per week and only those students that had a green pass for the day were allowed into the laboratory space. All students followed the social-distancing and disinfection protocols while they were in the lab space. The lab doors and windows were kept open during the entire lab session to ensure proper ventilation.

The 17 enrolled students were split into five groups of three students each and one group of two students. The students in the same lab group were required to work on neighboring stations, this allowed students in the same lab group to work in a collaborative environment while maintaining social distancing. The instructor observed that the students within the same lab group and working on neighboring stations frequently discussed concepts related to the laboratory experiment, circuit construction techniques, measurement techniques, and laboratory report writing.

Figure 2. Students building circuits, operating instruments, and analyzing data.

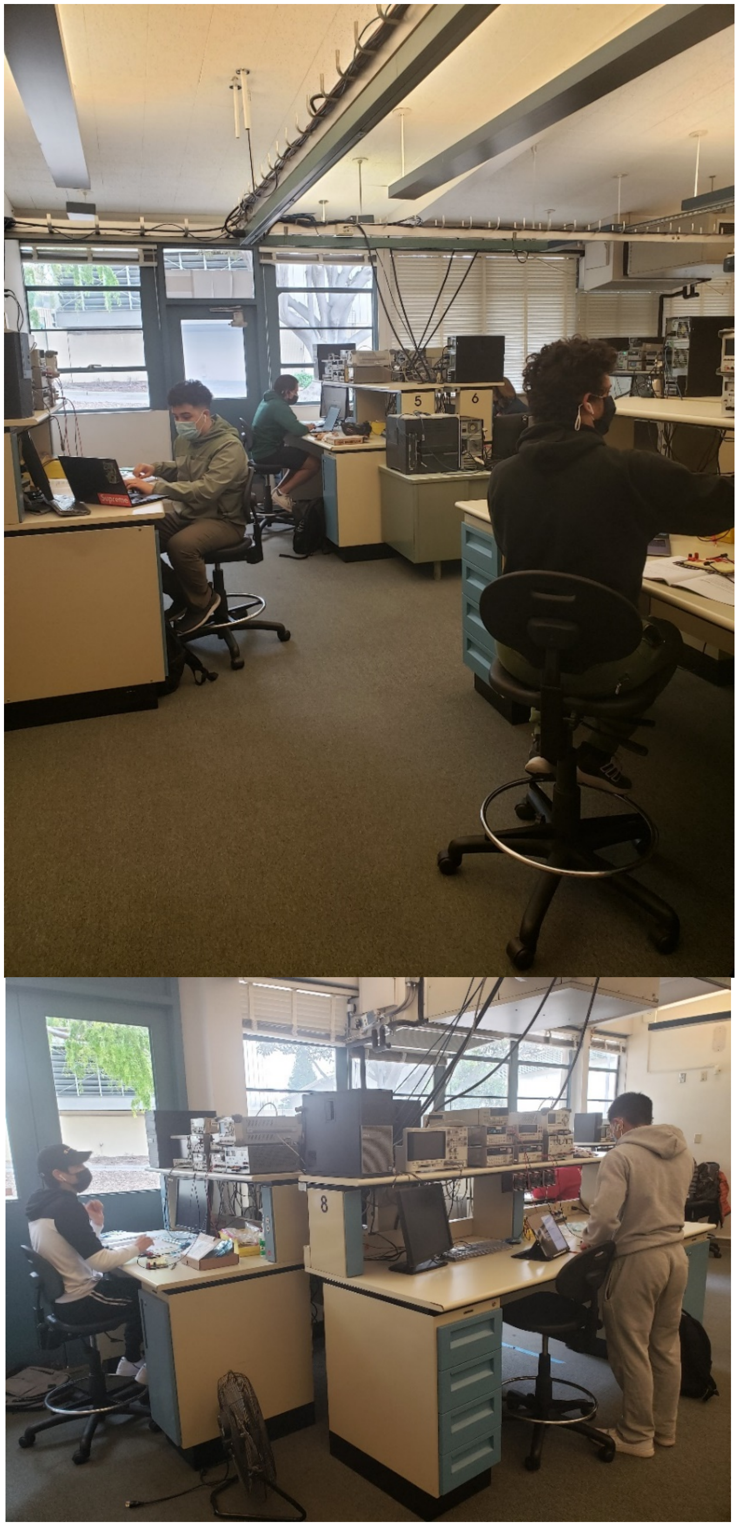

Figure 3. The laboratory benches are at least six feet apart.

All lab groups were required to submit a comprehensive lab report in PDF form within 72 hours of the completion of the scheduled lab time. The students were required to submit these reports through the course's Canvas page. The instructor also shared university assigned email addresses of all students enrolled in the course on the course's Canvas page. This allowed students to email each other and collaborate with each other on answering prelab questions, preparation for lab experiments, and writing of lab reports. The instructor also recommended the use of Google docs and Discord to all students for effective collaboration; however, the instructor did not provide any formal training or training resources on the usage of Google docs or Discord to the students.

Table 1. Question 1. I feel safe in the in-person lab.

	Strongly Agree	Agree	Neither Agree nor Disagree	Disagree	Strongly Disagree	Total number of Responses
Lab # 2	12	2	1	0	0	15
Lab # 4	13	2	0	0	0	15
Lab # 6	14	2	0	0	0	16

Table 2. Question 2. I feel confident in my ability to perform the lab by myself.

	Strongly Agree	Agree	Neither Agree nor Disagree	Disagree	Strongly Disagree	Total number of Responses
Lab # 2	6	4	4	1	0	15
Lab # 4	7	4	3	1	0	15
Lab # 6	7	8	1	0	0	16

Table 3. Question 3. I feel confident in my ability to follow social-distancing protocols in the lab space.

	Strongly Agree	Agree	Neither Agree nor Disagree	Disagree	Strongly Disagree	Total number of Responses
Lab # 2	10	4	1	0	0	15
Lab # 4	12	3	0	0	0	15
Lab # 6	11	5	0	0	0	16

Table 4. Question 4. I have anxiety in the lab space because of COVID-19.						
	Strongly Agree	**Agree**	**Neither Agree nor Disagree**	**Disagree**	**Strongly Disagree**	**Total number of Responses**
Lab # 2	1	1	1	4	8	15
Lab # 4	0	0	0	5	10	15
Lab # 6	0	0	2	3	11	16

Table 5. Question 5. I am happy with my decision of going with the in-person lab instead of virtual lab.						
	Strongly Agree	**Agree**	**Neither Agree nor Disagree**	**Disagree**	**Strongly Disagree**	**Total number of Responses**
Lab # 2	13	2	0	0	0	15
Lab # 4	14	1	0	0	0	15
Lab # 6	13	3	0	0	0	16

Table 6. Question 6. I feel confident in my ability to complete the lab reports virtually with my lab partners.						
	Strongly Agree	**Agree**	**Neither Agree nor Disagree**	**Disagree**	**Strongly Disagree**	**Total number of Responses**
Lab # 2	9	5	1	0	0	15
Lab # 4	7	4	4	0	0	15
Lab # 6	5	5	4	0	0	14

Table 7. Question 7. I was able to procure the lab kit without issues.						
	Strongly Agree	**Agree**	**Neither Agree nor Disagree**	**Disagree**	**Strongly Disagree**	**Total number of Responses**
Lab # 2	12	3	0	0	0	15
The same lab kit is used all 10 weeks of the course.						

Figures 2 and 3 show students working in an improvised traditional face-to-face laboratory setting during this COVID-19 pandemic. All lab stations were at least six feet apart and the students were required to have face coverings at all times. All students that appear in the pictures have voluntarily signed the university's Visual/Audio Image Release forms. The signed forms allow the university to use these pictures for university-sponsored websites, publications, promotions, as well as non-university uses.

Survey Design and Analysis of Responses

The study population were the 17 students enrolled in the EE 346 improvised traditional face-to-face laboratory course implemented during this COVID-19 pandemic. The survey was carried out using questionnaire printed on regular letter sized paper. The survey response was voluntary and anonymous. Student responses were collected at the end of: Lab # 2 performed in week 2, Lab # 4 performed in week 5, and Lab # 6 performed in week 7 of the 10-week quarter. Week 3 of the quarter did not have a lab scheduled because of an academic holiday. The first week of the course was virtual as the first experiment was designed for SPICE. Of the 17 enrolled students a minimum of 14 students responded to every survey question, this corresponds to a minimum of 82% response rate.

Tables 1 to 8 list the voluntary and anonymous responses received from EE 346 students. In general, the data suggests that as the quarter progressed students got more comfortable performing the lab experiments by themselves. This can possibly be attributed to students getting increasingly familiar with their laboratory surroundings and/or feeling confident in the social-distancing and disinfection protocols established by the university. As this is an introductory electronics laboratory course, students are introduced to newer laboratory equipment such as source-meter and newer features of familiar laboratory equipment such as XY mode on the oscilloscope. Working with newer/unfamiliar laboratory equipment or exploring unfamiliar features of familiar laboratory equipment can be challenging at first. However, as students make repeated measurements using newer instruments or new features of familiar equipment, they get more comfortable with the equipment. The instructor also observed that as the quarter progressed students' questions related to operation of lab equipment reduced. Even though the sample size of this survey is relatively small, this is still a promising result, particularly for universities and colleges that are looking forward to implementing some form of traditional face-to-face laboratory instruction during this COVID-19 pandemic and beyond.

However, survey responses to question 6 are slightly worrying. The survey response to question 6 suggests that as the quarter progressed more students struggled to successfully collaborate with their group members in writing of laboratory reports. Group work is an important part of engineering education as it allows students to learn teamwork skills as they work through their lab experiments and lab report writing exercises[32]. The laboratory reports constitute a major part of a student's lab grade and are also an important part of ABET's criteria for undergraduate engineering education. This decline in successful collaboration required for writing effective lab reports may possibly be because:

1. Students are no longer able to physically get together to work on their lab reports as they were used to in pre-COVID times.
2. Not all students have access to a computer.
3. Not all students have access to reliable internet services.

4. Not all students are familiar with web-based resources such as Zoom/Google docs/Microsoft Teams/Discord that can be used to collaborate on writing of lab reports.

Traditionally, students take notes and collect laboratory data using pen and paper. Pre-COVID-19 times allowed students to sit together on their lab stations or in the library to share their pen and paper notes and work together on their lab reports. However, sitting together and sharing pen and paper notes is no longer recommended because of the pandemic. This means that students now need to explore and learn newer ways to share data and collaborate in writing of lab reports. Therefore, it is important that students are introduced and possibly trained in online web-based resources such as Zoom, Google docs, Microsoft Teams, and Discord to allow them to effectively collaborate with their team members in writing of lab reports[33-36]. Economically disadvantaged students without computing resources should be introduced to university resources that may allow them access to a computer[27, 37]. Students in a group should be encouraged to establish some ground rules and team contracts that would enable the group to successfully complete their lab report writing exercises[38].

Conclusion

While non-traditional laboratories may appear as the immediate solution towards instruction of engineering laboratory courses during a pandemic, their shortcomings cannot be overlooked. With thoughtful planning it is possible to implement an improvised traditional face-to-face laboratory course in accordance with the county's Department of Public Health guidelines during a pandemic. This paper demonstrated the implementation of one such improvised traditional face-to-face laboratory course. It is important to note that even during the pandemic, many students remain interested in traditional face-to-face laboratory courses as they offer some important advantages particularly hands-on experience with expensive real world industrial equipment. Students' responses suggest that with experience they get increasingly comfortable working by themselves under social-distancing and disinfection protocols. However, student collaboration in writing of laboratory reports show signs of struggle. It is apparent that students need to be introduced and possibly trained in the usage of web-based resources such as Zoom, Google docs, Microsoft Teams, and Discord, among others for successful collaboration in sharing of laboratory data and writing of effective laboratory reports.

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