Teaching Case

Trajectories in Turmoil: A Case Study of Engineering Students' Reactions to Disruptions in Their Community of Practice

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***Abstract*—Introduction:** *The COVID-19 pandemic brought unprecedented challenges to universities when instruction had to shift entirely online. Universities were quick to survey their students about those challenges, and education researchers are now focused on building more effective online experiences based on student feedback.* **About the case:** *The loss of in-person instruction was difficult for engineering students in practice-based courses as they lost the courses' hands-on aspect, which is essential for reinforcing theoretical concepts. They also lost the support provided through daily interactions with their peers and instructors.* **Situating the case:** *Students in a required four-course practice-based mechanical engineering sequence shared their perspectives via reflective portfolio essays on how shifting to online instruction affected their ability to participate in their learning communities and negotiate meaningful learning experiences.* **Methods/approach:** *Through thematic analysis of the reflective essays, we applied the lens of communities of practice to put the students' responses into context.* **Results/discussion:** *The students' concerns varied depending on their position in the course sequence and the course; however, most students felt that the loss of in-person interaction was most detrimental and disruptive in the transition to online instruction and yielded communication and teaming issues.* **Implications and conclusions:** *Five implications arose from the results of this study, including recognizing the unique challenges of online learning in practice-based courses, instructing students in virtual communication tools, exercising empathy, being mindful of cognitive load, and researching self-directed learners in online environments. In addition, faculty should consider the importance of students' communities of practice and build opportunities to maintain and strengthen the bonds of those communities within their courses, both online and face to face. They should also add more opportunities for virtual interaction early in the curriculum to build digital communication skills, which will undoubtedly be required in their careers.*

Index Terms*—Communities of practice (CoPs), engineering communication, practice-based online learning, teaming.*

This case analyzes how mechanical engineering students perceived the impact of a rapid shift to virtual instruction on their abilities to communicate with their instructors and peers, and the way that the experience affected their learning. Although a few undergraduate engineering degree programs are partially or entirely online, it is rare for mechanical engineering practice-based classes to be taught online due to the discipline's hands-on nature. Thus, students likely had limited online learning experiences as universities shifted instruction to virtual platforms when the COVID-19 pandemic hit the US in March 2020 [1]. Many universities conducted surveys of students during the transition and found that many struggled with poor internet access, inadequate instruction, or personal issues, such as housing, illness, or family concerns. In addition, being amid a pandemic had significant mental health impacts for students that may have played into the relationship between hands-on remote laboratory experiences and student perceptions. During the SARS pandemic (2003), a survey by Wong et al. [2] found that all students reported high levels of perceived stress and fear of the unknown, indicating the need for universities to implement mental health support programs.

One aspect of interest to engineering educators, especially those focused on communication and teaming instruction, is how communication functions—or does not function—in virtual learning environments. Using Lave and Wenger's community of practice (CoP) framework, we view students as moving through one community and

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Practitioner Takeaway

- Communities of Practice (CoPs) support engineering students during stressful times such as the COVID-19 pandemic, both formally in interactions with instructors and informally with fellow students.
- Engineering students relied on their CoPs for guidance in coursework, structure in their day-to-day lives, and emotional support, although this reliance was often not noticed until it disappeared with the abrupt shift from in-person to virtual instruction.
- Faculty can and should build community into their courses from the beginning by facilitating opportunities for questions and answers in non-threatening environments such as anonymous discussion platforms and by encouraging frequent student-to-student interaction, especially in online courses.

into another [3]. This framework argues that learning does not happen in isolation; instead, novices learn more effectively through social practice with other novices and experts to work through situations together. In higher education, students are members of at least two communities simultaneously: as members studying a particular discipline and as aspiring professionals, such as mechanical engineering students moving through the curriculum at varying academic stages and moving toward becoming mechanical engineers themselves. These two trajectories were disrupted by the rapid transition to virtual instruction, causing extra anxiety on top of the many concerns already cited in outlets such as *The Chronicle of Higher Education*, including family concerns, lack of quiet study space, lack of adequate internet access, and out-of-date hardware [4].

This teaching case explores how students perceived the loss of opportunities to practice in the laboratory, with a particular focus on the language that they used to describe the effect on their learning. Of specific interest to those who study communication in educational contexts is how students articulated their concerns about losing face-to-face (F2F) interactions with their peers, faculty, teaching assistants, and teammates. This study's vehicle is a student-curated reflective portfolio in a four-course sequence within a large (1450 students) undergraduate mechanical engineering degree program.

This portfolio requires students to rework and correct three assignments from the course sequence and compose a one-to two-page reflective essay addressing question prompts tailored to each course. Due to COVID-19, questions were tailored to have students reflect on the impacts of remote learning on their academic experience. Reflective portfolios were submitted electronically and graded by the course teaching assistants using a detailed rubric, based on students addressing required questions and including the correct number of assignments. No feedback was provided to students, and portfolios were cumulative over the four-course sequence.

This case study explores three questions based on responses from these reflective essays, which are as follows.

1. What relationships could be identified as important to the student's learning, and how did the disruption of those relationships affect the student's perception of his or her learning?
2. What steps taken by the student or the faculty/graduate teaching assistants (GTAs) helped (or could help in the future) in maintaining and strengthening those relationships in virtual or hybrid environments?
3. How can communication and teamwork be strengthened in an online environment to maintain CoPs and enhance their learning value?

The benefit of exploring these questions via student reflections lies in more effectively engaging students with their courses, degree programs, and eventual careers. By more fully understanding students' experiences in these classes as they transitioned to virtual formats, educators can incorporate the lessons learned into course design.

The next section provides context for this case study with details regarding the courses involved. We then situate the case within the phenomenon of CoPs and the ways that they function in online learning, engineering education, and hands-on courses. We also discuss the methods used to obtain and analyze student perspectives. The

TABLE I
MECHANICAL ENGINEERING PRACTICE COURSE INFORMATION

Course (Credits)	Team-based Work?	Course Description	Course Structure
MEP I (2)	Yes	Students develop laboratory and computer skills, Topics include product dissection, data acquisition, materials testing, 2D finite element modeling, 1D modeling, and simulation. Hands-on physical interaction with hardware.	1 hour of traditional lecture; 2 hours of hands-on practice session per week
MEP II (3)	Yes	Students further develop testing and simulation skills as they validate dynamic mechanical and thermal/fluid systems. Course emphasizes application of energy conservation principles to physical engineering and control systems and analysis and communication of data and design validation. Hands-on physical interaction with hardware.	2 hours of traditional lecture; 2 hours of hands-on practice session per week
MEP III (2)	Yes	Students apply the engineering design process by combining engineering science with simulation tools to guide design decisions. They use energy-based models to determine design direction and design-based simulation to select and optimize components and subsystems to meet design requirements. Solely software and simulation-based.	1 hour of lecture – flipped classroom; 2 hours of simulation-based practice session per week
MEP IV (3)	No (Data acquired in a team, assignments are individual)	Students create simulations and validation procedures to verify that components and the assembled system meet desired requirements, focusing on dynamics, vibrations, and controls. Experimental methods, simulation, data processing, comparing experimental and analytical results, and engineering communication methods are emphasized. Hands-on physical interaction with hardware is complemented with simulation activities.	2 hours of traditional lecture; 2 hours of hands-on practice session per week

resulting two main themes, perceptions of the disruption and communication issues, and their implications for enhancing online communities in traditionally hands-on courses are then presented, followed by implications and future research.

ABOUT THE CASE

This case is situated at a small (5800 undergraduate and 1375 graduate enrollment) public US university. The mechanical engineering undergraduate program population is homogeneous, with more than 95% identifying as white and less than 15% as female. All students in the BSME program must take the Mechanical Engineering Practice sequence described below.

The Mechanical Engineering Practice course sequence allows students to apply concepts that they learn in theory courses, such as statistics, dynamics, thermofluids, vibrations, and controls to practical activities mimicking what engineers do on the job [5], [6]. Titled Mechanical Engineering Practice I, II, III, and IV (hereafter MEP I, II, III, and IV), each of these semester-long courses has varying credits and structure (see Table I). Early in the sequence, students view these courses as challenging and labor-intensive due to the technical content and open-ended design problems. Toward the end of the sequence, students have matured to appreciate these courses' value in providing exposure to real-world engineering problems in an academic setting.

All of the MEP courses focus on open-ended design projects with consistent experiments and assignments each semester, with varying values or requirements to ensure unique solutions. The experience is based on real exploration using experimental data to assess behaviors and design physical systems to meet specific requirements. Engineering theory and simulation support

observations and conclusions from experiments in the practice sessions. In a typical semester, students attend live lectures focused on theory, participate in practice sessions to acquire and analyze data, and master the requisite technical content. With the transition to virtual learning, hands-on practice sessions were replaced with asynchronous videos of GTAs completing the activities, and students were provided with data to download. The exception was in MEP III, a simulation-based practice course that already used a flipped classroom model; the only change with remote instruction in this course was the absence of an interactive synchronous practice session to apply lecture content to their simulation project.

We wanted to understand better how students perceived their experiences in these hands-on laboratory-style classes given the rapid transition to an entirely virtual environment, with a particular focus on students' CoPs, communication, and teaming. Just as the transition was not planned in advance, this study arose from necessity with the expectation that virtual instruction would continue in later semesters. This case study demonstrates how students viewed communication with their faculty, GTAs, and peers concerning their learning, and presents ways that educators could build healthier learning communities regardless of content delivery mode. We observed that many students perceived the transition from in-person instruction to virtual education as harming their ability to learn and retain the material. They also struggled to communicate with peers and ask questions of their faculty and GTAs.

Situating the Case

Educators first applied a CoP framework to engineering programs in 2003 when Rover reviewed two books on CoPs for the *Journal of Engineering Education* [7]. In her review, she indicated an increased interest in how community functions in engineering programs. Later that same year, she led a panel discussion at the Frontiers in Education conference that explored the ways in which learning communities were enhancing education, research, and society [8]. Since then, researchers have built a richer understanding of how CoPs can improve teamwork and professional skill development [9]. While not referencing CoPs, Martinez et al. found that adding online resources, such as web-based academic guides, time and academic record-tracking tools, message boards, and blogs, reduced drop-out rates in a fully online engineering master's degree program [10].

The current case study focuses on students enrolled in the four-course practice sequence during the COVID-19 pandemic that forced a widespread transition to virtual learning. These students had established CoPs during their F2F academic experiences, which were abruptly disrupted during the pandemic. The impacts of this disruption were gathered using a pre-existing reflective essay assignment tailored to understand the influence of virtual learning, as outlined in the subsequent sections.

Online Learning and CoPs When deciding to attend college, students place themselves on a trajectory toward a goal. Along that trajectory, students become members of CoPs [11], such as students in the same discipline, aspiring artists, amateur athletes, and musicians. Snyder and Wenger state that "the activities of a CoP differ along several dimensions—F2F to virtual; formal to informal; public to private" [12, p. 110]. These activities also have "rhythms," such as class schedules, team meetings, and assignment deadlines. Through these interactions and activities, students build their communication, teamwork, and technical skills by sharing knowledge and reinforcing a sense of belonging in their discipline—that is, their identity as "becoming" engineers. One aspect of developing that identity is through a learning trajectory [11]. Wenger pinpoints four types of trajectories; this case study focuses on two: inbound, where students are moving toward becoming mechanical engineers, and outbound, where students are moving away from college student status to practitioner.

Johnson and Johnson found that students who participate in supportive communities, such as cooperative learning, experienced higher achievement, improved retention, and greater intrinsic motivation [13]. Universities facilitate and strengthen these communities through student organizations; spaces, such as residence halls and gathering places, career and academic counseling that promotes peer networking; and events that bring people together. However, what happens when those bonds are suddenly weakened, such as when a university has to shut down and shift from F2F to virtual instruction with little warning? How does the weakening of those bonds affect students'

perceptions of their trajectories towards their goals?

The current study focuses on undergraduates experiencing a sudden disruption to their educational trajectories at an essential point in their degree program, moving from hands-on, active learning to virtual learning in isolation caused by the COVID-19 pandemic. Of course, this university was not alone in this dramatic shift. The pandemic forced a rapid adjustment of society to control the spread of the infection and resulted in a quick transition from F2F instruction to virtual instruction in the space of just a few days for many universities. In the weeks that followed, many professional societies to which higher education faculty belonged hosted webinars on how faculty with little or no experience with teaching online could make their courses more engaging for students, using a range of technology. This support system—a CoP—in addition to their universities' centers for teaching and learning, helped faculty make the transition more smoothly. However, students lacked a built-in support system, despite being members of a critical CoP themselves—in this case, aspiring mechanical engineers. Other than some brief tutorials from the centers mentioned earlier and encouraging emails from faculty, chairs, deans, and provosts, students entered this new learning environment with few resources to help them adapt.

We have no specific numbers to indicate precisely what percentage of faculty and students had prior experience with online teaching and learning. However, from the outpouring of webinars relating to online teaching techniques in the weeks that followed the transition, it is safe to assume that many faculty struggled with the effort, as did their students. One area of particular concern was how to transition laboratory-style courses to a virtual format. Engineering curricula are replete with hands-on, practice-based courses that emphasize theoretical concepts that might otherwise be difficult to fully grasp without the opportunity to see, touch, and hear the concept applied in reality. Engineering often appeals to students who describe themselves as kinesthetic learners; that is, they prefer to learn through hands-on activities engaging multiple senses [14]. Thus, it should not be surprising that our students expressed high anxiety at not learning material via the methods they find most compatible [15]. However, to call the experience stressful without delving into the sources of that stress does a disservice to the students and to online education. We argue that one aspect that made this particular transition so difficult for students is that they lost access to a critical component of their lives—their CoPs.

To date, CoP has been used as a lens in technical communication to examine such topics as social media [16], video games [17], and the workplace [18]–[20]. This study differs in that it explores the ways that undergraduate engineering students describe their experiences when forced to quickly shift from a mode of instruction with which they are most comfortable to one to which they may have had little prior exposure. This study reveals the role their CoPs play in helping them adjust to the challenges and consequences of losing ready access to their CoPs.

Value of Reflection in Engineering Education

As demonstrated by our program's use of portfolios [21], reflection can be a powerful learning tool. Moon describes reflection as

> a mental process with purpose and/or outcome in which manipulation of meaning is applied to relatively complicated or unstructured ideas in learning or to problems for which there is no obvious solution [22, p. 155].

However, although Dewey first advocated for the inclusion of reflective practices in education more than a century ago [23], [24], its engineering education value was not fully recognized until recently [25]. McAlpine et al. view reflection as a continuous interaction between the two interrelated components of action and knowledge [26], which makes reflection helpful in building student confidence in their ability to connect what they have learned (knowledge) to what they can do (action or practice) [27], [28]. Reidsema and Mort found that effective reflection includes detailed explanations and critiques of the learner's process as opposed to praising it—for example, a student would be more detailed by writing "I need to work on communicating to my team when I need help," as opposed to the less expressive "I work well in teams" [29]. Furthermore, portfolios effectively support self-authorship in engineering students [28], enabling students to make conscious decisions about what they value and believe rather than accepting values and beliefs imposed on them without critiquing those ideas [30]. Thus, these reflective portfolio essays provided the artifacts for this study, as explained in the next section.

Methods/Approach

Reflective Portfolios In their reflective essays, students are asked to respond to a series of questions related to their perceptions of what they learned, what they will do to continue building skills, and how course instruction, content, or structure could be improved. With the rapid transition from F2F instruction, the reflective essays provided a unique opportunity to understand how that transition impacted our students' perceptions of their learning. Thus, the following three questions were substituted for existing questions in all four MEP courses.

1. In what ways has the shift to online-only instruction impacted your learning?
2. What has been your biggest challenge these last seven weeks?
3. How can the university (faculty, staff, GTAs, community) help you continue to progress toward your educational and career goals when you return to campus in the fall?

Their responses were analyzed using the qualitative method described in the next section.

Thematic Analysis We used thematic analysis to analyze the essay responses to the questions above [31]–[34]. A qualitative research methodology, such as thematic analysis, is useful in analyzing texts, such as essay responses, because it goes beyond simply counting types of responses (e.g., *X* number of people said yes, while *Y* said no). Weisse notes that qualitative methods work best when researchers want to capture in-depth information to understand the respondent's position [32]. Boyatzis describes thematic analysis as a process for encoding qualitative information, which requires explicit codes. These may be

> a list of themes; a complex model with themes, indicators, and qualifications that are causally related; or something in between these two forms [34, p. 4].

One benefit of examining the student responses using thematic analysis is that it forces researchers to go beyond induction "by developing a theory that is not a simple synthesis of observational statements" [35, p. 9]. Although this method does not rule out scaling or scoring themes to provide an overall description of results or confirmation of those results [34], this analysis process helps develop a deeper understanding of the data. Thus, we can justify that what we observe about the data is grounded in an objective investigation; that is, others would likely draw similar conclusions from examining the data in question. Given that engineering educators are usually trained to value deductive, empirical research, applying such rigor to qualitative research can make results more acceptable for reviewers in the field [36]. Thematic analysis allowed us to give the students a voice in their learning and speak freely about their concerns as they navigated this difficult transition in their education.

We analyzed the essays to determine common themes. When reviewing the essays, we first skimmed all submitted essays for content and then focused on students' responses to the questions about the impact of COVID-19 on their semester. We disregarded superficial responses and analyzed only those with substantial insight. Coding was not used to reflect on themes; instead, we both reviewed and highlighted commonly observed themes as supported by student quotes.

Results/Discussion

This section focuses on student perceptions of the rapid shift to virtual learning and ways that these perceptions relate to CoPs. However, before discussing the students' perspectives, it will be helpful to understand how CoPs function in the MEP courses. Wenger defines practice as including the explicit and tacit elements of a situation; that is, what is documented and what is not [11]. In these practice-based courses, each session has documented instructions to follow, and GTAs familiar with the equipment to provide insight into what can go wrong or ways to make a device operate more effectively. A student's peers serve similar functions, such as providing help with a concept that they have mastered already or a way around a software issue. Thus, GTAs and peers provide a crucial resource and foundation for these CoPs.

One element of practice is the negotiation of meaning, a phrase that Wenger uses to "characterize the process by which we experience the world and our engagement in it as meaningful" [11]. This negotiation takes place over time and builds a scaffold of knowledge, as evidenced by students progressing through their curriculum to become mechanical engineers. Although the process of negotiating meaning does not require F2F interaction, Wenger argues that active participation with peer groups is vital to successful integration into a CoP. In addition, the nature of that participation (virtual versus F2F, frequent versus infrequent, and casual versus formal)

shapes the participant's and community's experience [11].

However, the process of making meaning from our experiences requires more than merely participating in the company of others. It also requires what Wenger calls "reification," which he describes as giving form to an understanding through

> making, designing, representing, naming, encoding, and describing, as well as perceiving, interpreting, using, reusing, decoding, and recasting [11, p. 59].

Students reify engineering concepts through interacting with tools and technologies in the practice session, through formal discussions with instructors and GTAs, and informal discussions with peers. If learning objectives are met, students move from the student identity to the professional engineer identity. In their essay responses, the students echo these three components—meaning, participation, and reification—in their concerns about mastering and applying material.

The responses highlighted here demonstrate how they perceive that the disruption in their learning environments affected their CoPs and their ability to learn and retain the material. Rather than present the results as responses to each question in the essay, we synthesized the responses into two critical themes regarding how students perceived certain aspects related to the trajectory of their education and communication within their CoPs, that is, classroom and peer groups. The first theme, perceptions of disruption, characterizes students' insights into the effect that the transition to virtual instruction had on their learning ability. The second theme, communication issues, highlights students' observations on communication (both between peers and with the instructional team) and teaming in a virtual environment, including challenges and lessons learned. The comments included have been lightly edited for clarity only, (correcting spelling or grammar only when necessary, and omitting irrelevant language).

First Theme: Perceptions of Disruption How students perceived the disruption caused by the shift to virtual instruction varied depending on two factors: the structure of the course (how much support students needed to complete assignments) and their position on the trajectory toward graduation (the more advanced, the greater concern they expressed about reaching their postgraduation goals). See Table II for sample responses.

Consistent across all courses, students discussed how distractions impeded their ability to focus on course content online versus F2F. Some cited general distractions, such as family, or more severe issues with illnesses or events, such as moving to a new home and a grandparent breaking a hip. Other students were less specific about distractions, indicating that it was more challenging to focus on lecture videos than attending class in person. Some students said that they tackled this problem by trying to set strict time schedules. Others suggested that faculty make use of synchronous Zoom class sessions and require student attendance at the same time as the scheduled class would have occurred in person, to support a consistent routine.

The main concern expressed by MEP I students was how the loss of hands-on experience in doing the labs would affect their retention of the material in future classes. The two comments for this course shown in Table II demonstrate that the loss of in-person interaction, which is tied to the CoP, combined with the loss of physical interaction with the course's tools and technology, made learning a struggle. In addressing this concern, many students recommended that faculty in subsequent courses that build on MEP I include extra review sessions on major concepts and be flexible and "understanding" in their expectations of student performance as they may be less likely to retain key concepts.

Most students in MEP II also felt that their learning had been negatively impacted by the transition but were more likely to cite a lack of motivation for attending to school work as a critical factor. Motivation is one area where we see CoPs playing an essential role because students often lack motivation and use peers to hold them accountable. Another factor was loss of their daily routine—the act of going to class, seeing professors, and doing homework in the library or computer laboratories.

As noted earlier, MEP III already had a significant virtual component in that the course content focuses on simulation and modeling, and the class (F2F) was already using a flipped-classroom model. However, these facts did not alleviate students' stress in the transition; instead, it added to their stress levels because of difficulties in accessing and running the software from home. Beyond IT-oriented issues, such as computing capabilities and compatibilities, students' stated that the loss of in-person guidance in troubleshooting software glitches was problematic. Once again, the loss of

TABLE II
SUMMARY OF STUDENT PERCEPTIONS ABOUT THE DISRUPTION BY COURSE (# OF ESSAYS ANALYZED)

MEP I (53)	MEP II (170)	MEP III (75)	MEP IV (160)
I am a very hands-on person and take and remember new information better when it is relayed to me in a conversation person to person. Also, when I can ask a small question and get an immediate explanation as to why our data is graphing the way it is or something else small, that bolsters my overall understanding of the concept.	It is difficult to wake up in the morning and to be productive when I know that I am only going to be sitting in my room all day. It is easy and convenient to speed through lectures and only absorb the relevant information but the act of sitting in a lecture hall and listening to a teacher teach at their pace seems to make retention easier.	In the earlier part of the semester my group and I had issues getting our MotionView simulations to run on the computer in person due to the pulleys required. This issue only became more magnified as we transitioned to online, and had to remotely connect to the software.	… I … am more productive and efficient when I am in an environment that is productive. Being locked in my house has been a struggle to make sure the quality of work is even close to the same level. … Next year, grades are going to suffer. The material from these last seven weeks was not as well comprehended, and it won't be as well retained. Any class that intends to build off of previous material will be difficult...
… being separated from the lab work caused a … disconnect from what I was doing, and the skills I was learning. … I have used a lathe before but utilizing the online lathe interface … made the process much slower and more confusing… if the physical lathe [were] in front of me, I would have understood and implemented the lesson materials better.	… What keeps me engaged sometimes is the enthusiasm of the professors, social interactions with friends relating to the classes, and even just having a separate learning environment other than my bedroom. It is hard for me to find class material exciting by myself.	… had issues [running] our MotionView simulations [that were] magnified as we … had to remotely connect to the software. I personally had a lot of issues using the FEA meshing, as most of the time when I needed to rotate or move a part the software would crash and I would have to start all over again.	… I'll be applying to full time positions in the fall, so I'd like to see continued support for graduating students to find a career they're happy with. … I think the biggest potential impacts in the fall are the Career Fair, making sure that students can make those connections for full time positions, ...

in-person, immediate assistance proved challenging when the technology failed to work as expected.

Students finishing MEP IV are typically two semesters away from graduation. Thus, it is not surprising that of students in the four practice courses, they were most likely to express concerns about how this disruption would impact their ability to complete their final year of the program and find a job after graduation. This fear was expressed in terms of expectations of low grades in subsequent semesters because they would be unable to retain and apply what they had learned and that the career fair would be disrupted.

Second Theme: Communication Issues

Students expressed the important role that their CoPs played in their learning through their descriptions of communication challenges within their teams and with instructional personnel after moving to virtual instruction. Although most students who mentioned team communication indicated that they overcame any issues, many still found the virtual-only format less satisfying and productive when completing assignments. Students need to be taught ways to effectively and efficiently engage their peers in a virtual teamwork environment. Communicating with faculty and GTAs proved most problematic when instructional personnel were not responsive or when the student needed help with a software problem and screen-sharing proved inadequate. Table III presents sample essay comments from the four courses revealing the challenges with virtual communication and ways that the students attempted to learn to adapt, with key elements discussed next for each course.

MEP I and II include both team and individual assignments, and most of the students in this case study's class are in their second year of college.

TABLE III
SUMMARY OF STUDENT COMMENTS ON COMMUNICATION ISSUES BY COURSE

MEP I	**MEP** II	**MEP** III	**MEP** IV
… I think that communication was definitely a greater challenge during the shift to online learning and the lack of being on campus and having the necessary available resources all in one spot was a big change. Whether it was being able to walk to a professor's office to ask questions or meet up and collaborate with other students …	Despite having an instant message platform that [my group] used to discuss deadlines and progress updates, ultimately sitting down and discussing each project via a video chat became the most effective way to problem-solve each week.	… being in front of a computer screen all day and during late-night hours, without in-person communication about my degree makes learning quite dull and unproductive. Likewise, office hours online are not the same and asking questions has been difficult and most of the time instructors are unresponsive.	… being stuck home took away any support groups that students had formed throughout the semester. Many times I felt alone and confused on an assignment I couldn't figure out.
The biggest challenge for me was receiving timely feedback on my work. For example, I was working on the Virtual Lathe Report recently, and felt alone in the process. … I recommend a system that allows TA's to become more interactive with the students, such as an occasional help session outside of the scheduled practice session time.	Learning to work with people through non-face-to-face contact was a challenge my group had to overcome. We got into the routine of doing a zoom call whenever we were finishing an assignment, because while we were not allowed to meet in person, verbal communication was still the fastest way to get work done.	While virtual methods of communication allow for team assignments to be carried out, I have come to more fully appreciate the potential efficiency of face-to-face team interactions. Additionally, I found it much more challenging to receive answers to questions I had regarding the use of software for completing tasks assigned for the course.	… it was harder to communicate my issues to the teaching team, as well as it being harder for them to help. While on campus, it was easier to show up to my GTA's office and directly show where I was at and what problems I was having. Once everything was online, it was much harder to quickly figure out and fix problems to continue moving forward.
… I feel I did miss out on some useful experiences. The biggest online learning challenge was learning Hyperworks without being able to consult with my group or instructors.	The biggest challenge with online learning is maintaining class participation. So keeping up with class got harder, it was also harder to communicate with professors because there isn't direct contact communication so there would be time wasted between question and answer. And sometimes they interpret the question wrong so even more time is wasted	… the importance of in-person communication. It is much more powerful and helpful for a team dynamic. … Having to communicate over the internet has made me make sure that I am reading through emails and other online communication more closely … since there is no nonverbal communication it is difficult to fully understand someone.	I do wish there was more contact [with faculty] … via zoom or phone calls. Personally, I prefer verbal communication and discussion to learn new topics compared to writing. I also wish there was a way for me to point to things in front of me during these online communications.

Thus, they have some experience working on large projects for extended periods in teams, but less so than more advanced students. Still, the transition to virtual instruction proved especially challenging for students who needed more interaction with GTAs and their peers, with more than one student saying they felt “alone.” However, a few students mentioned the importance of building virtual skills for future professional applications—that is, moving toward becoming a mechanical engineer—thus highlighting the need for students to be taught these tools and opportunities to practice them.

Past students have often described the MEP II course as the most difficult in the sequence because of the amount of work and the content's complexity. As a result, significant peer interaction, communication, and teaming are vital for completing assignments and understanding the material [37].

Students more advanced in the curriculum were more likely to cite specific issues with the loss of peer and instructor interaction. The team-based aspect of MEP III proved challenging; most of the students indicated they had to put extra effort into managing the loss of in-person assistance with the software and communication with their teammates. Ironically, despite the fact that MEP IV did not have a teamwork component, students frequently cited the loss of peer contact as problematic. One reason could be that, as this was at least the sixth semester of their degree program, they had formed a strong community with their classmates in earlier courses in the sequence. In addition, although assignments are completed individually, data in the practice session are acquired by students working in teams. These unofficial teams are another community formed by students to help contribute to their success.

The lack of in-person access to instructional personnel and peers that left some students struggling to complete their work was a common theme in the comments. This result comes even though members of this generation of students are often described as "digital natives" because they grew up with digital communication tools, such as social media, and are more comfortable with digital technology [38]. However, more research is needed to understand how students view virtual communication to build meaningful relationships and learning. The next section focuses on five additional implications of this study.

Implications

Educators benefit from a more in-depth exploration of student perspectives beyond the ubiquitous surveys and course evaluations conducted at the end of the spring semester/quarter, which can be accomplished through qualitative reflective methods, as demonstrated in this study. These results show that faculty must build, maintain, and strengthen community bonds within the courses to support students' learning journeys. If we allow ourselves to see students as experts on their own learning needs, we can find value in their suggestions for improvement. In addition to sharing their concerns, students also had suggestions for helping faculty improve course content and delivery regardless of whether it was virtual or in-person. Based on the students' responses, we recognized five clear implications of this case study for faculty interested in designing courses that effectively engage students with the material and with each other.

Realize the Unique Challenges of Online Learning in Practice-Based Courses Courses that rely on hands-on activities to teach concepts require much more planning for a virtual format. Gilbuena et al. [10] found that feedback on professional skills practiced in project courses helped students move further along the trajectory from legitimate peripheral participant, as described by Lave and Wenger [3], toward a professional identity as an engineer [11]. Therefore, transitions to virtual laboratories need to be adequately assessed to evaluate the impacts on student learning and ensure that the benefits of project-based courses are upheld in the online environment. This research would involve comparing a remote to the standard F2F course and comparing students' learning outcomes. Though various pathways exist to implement virtual laboratories, and others are continuously being developed, the impact on students' learning has yet to be widely studied and understood [39]. Furthermore, these remote or virtual hands-on activities must be developed in such a way to improve students' understanding, application, and retention of the material, and they require opportunities to reflect on the material to promote improved and deeper insights [40]. This implementation could be modeled on the structure used by Ferri et al. [41], which include prelaboratory assignments focused on individual analytical work, a practice session virtual experiment, and then reflective work (reviewing and analyzing experimental results and preparing an assignment deliverable).

In addition, these online environments for practice-based courses must be designed to uphold and strengthen CoPs that are essential for student learning and knowledge retention. Also, remote laboratories should include realistic experiences, including any videos and remote laboratory interfaces, such as real devices that would be implemented within the hands-on environment [42]. Simulations have merit, but they must be developed such that their value and relatability are apparent to students to facilitate the learning experience.

In addition, online environments must be designed to uphold and strengthen CoPs essential for student learning and knowledge retention. This could be accomplished by mixing individual and group work experiences in remote environments, facilitating interaction, and teaching students to efficiently and effectively take advantage of their CoPs. Corter et al. found that individual data collection was best for remote experiences, whereas F2F learning outcomes were improved when students worked in groups for data collection [43].

Teach the Use of Virtual Communication Tools Students need explicit instruction and practice in virtual communication, which should be incorporated into classes utilizing teams for activities and assignments whether the course is F2F or online. Topics to address include frequency of communication, tone, professional videoconferencing protocols (backgrounds, use of microphones/headsets, camera positioning, etc.), and access to tutorials on advanced features of commonly used platforms, such as Zoom, WebEx, Skype, and Google Meet. Note that many comments included here cite early struggles with technology. Practice and instruction in these technologies before their use in an emergency can alleviate some of that stress. One way to do this is by offering students virtual office hours from the beginning of the course and requiring them to check-in at least once early in the semester to get comfortable with the technology and format.

Consider the Importance of Empathy As evidenced by so many students who indicated dissatisfaction with virtual communication effectiveness, faculty should explore how empathy factors into such interactions. Empathy includes perceiving others' feelings, behaviors, and motivations [44], and it is vital to successful team performance [45]. Walther et al. argued that empathy-building needs to be included explicitly in engineering courses. They developed a series of modules that

> prompted students to consider, question, and try to make sense of the roles others would play in their engineering futures and the ways in which the students would engage as professionals with stakeholders or colleagues. [44, p. 19]

Empathy can be built through increased student-faculty engagement virtually via collaboration tools, such as discussion boards, virtual office hours, and quick email responses, as well as increased flexibility and mutual understanding of the stress that the current situation has placed on everyone.

Be Mindful of Cognitive Load Another aspect to consider in online and blended learning is cognitive load. Many students indicated feeling overwhelmed by the initial transition from F2F to virtual instruction, in part because some faculty increased the weekly workload by adding quizzes or assignments. Although the intent was to keep students engaged in the course and substitute activities for hands-on sessions, many students, already struggling with technology and the pandemic's mental health effects, had difficulty keeping up with the extra load. Many students indicated that they had no prior experience with online classes, so they were thus novice learners in this new environment. Research shows that adding to an already high cognitive load, such as that experienced in engineering courses, can lead students to become frustrated and fail to learn and retain information adequately [46]–[48]. Faculty should establish consistent schedules and formats for assignments, set a limited number of clear learning objectives from the beginning of the course, and ensure that all activities and assignments aim at achieving those objectives [49]. If faculty reduce unnecessary cognitive load, students can better focus on their relationships with peers and instructors, reaping the positive benefits of their CoPs.

Self-Directed Learners Can Thrive Online Finally, when building teams, faculty should consider whether a student identifies as a self-directed learner—someone who views learning as a journey and plays an active role in reflecting on their level of knowledge and subject mastery [50]. Less than 5% of students in each class preferred the online format because they could work at their own pace. These students felt that they learned more effectively when they could repeat or fast-forward through sections of the prerecorded videos and independently find supplemental resources. That is not to say that they are less reliant on their CoPs. Instead, the link between self-directed learning and CoPs needs further research. A few studies have shown that although often viewed as intrinsic [51], self-directedness can be increased through advising and reflective activities, such as asking students to journal about their learning practices in the course [52], [53].

Conclusion

When universities ended in-person classes in March 2020, they tried to minimize the effects by continuing courses online. However, this transition disrupted the CoPs established by and for engineering students in the middle of their undergraduate degree programs. As evidenced by thematic analysis of their reflective essays, students in this case study indicated that this disruption had both negative and positive effects. They lost the ability to instantly get answers to questions and interact informally with peers, substantially reducing the effectiveness of their CoPs. However, many also indicated that they learned to communicate more effectively electronically and forced themselves to take more responsibility for their learning without the day-to-day routine imposed by on-campus courses.

Because the pandemic may lead to a paradigm shift in how we all engage in work—F2F or virtually—faculty should build virtual communication experiences into their F2F courses and design their online courses with community-building aspects and diverse learning styles factored into the structure from the beginning. Limitations of this teaching case involve thematic analysis of reflective essays focusing on only one semester's experience. A more conclusive understanding of themes could be gained by following a cohort of students through the program and performing a semester by semester thematic analysis of their essays. It would also enable characterizing how student perceptions and reflections evolve during the sequence. This would require a sequence of four semesters of online course delivery in the MEP practice sequence, which may not be feasible. Finally, the same questions will be asked in the fall 2020 sections of the courses studied here to gauge whether the adjustments that faculty made to their courses improved students' sense of community and learning.

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