Chapter 12
The Formation of Engineers in Research Labs during the COVID-19 Crisis

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12.1 Introduction

In recent years, pedagogical approaches to learning in higher education have gradually shifted away from didactic, lecture-based instruction to *pedagogies of engagement* that focus on turning students into lifelong, creative, and innovative learners. The pedagogies of engagement, which have their roots in Deweyan progressive education movement (lining experience with reflection and understanding with doing; Dewey 1933, 1938), embrace students' engagement and direct their experiences with methods and processes of inquiry and experiential learning (Edgerton 1997; Thompson 2014). The pedagogies of engagement no longer view educators as dispensers of knowledge and information, but as facilitators of learning who help

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students stay engaged and hone their self-regulation, deliberate practice, and deep learning skills (Hodges 2015; Lang 2016).

It is within the pedagogies of engagement that we can see an important role that authentic research experiences play in high-quality engineering education and STEM education more broadly. Real-world research settings have been considered as a model of how students should learn, and engineering pedagogy experts recommend courses that imitate research laboratories or place students in working laboratories to experience authentic research. However, the recommendations for such research experiences have not received the rigorous examination they deserve, given their increasing prominence in engineering pedagogy.

Most of the previous studies on students' research experience focus on undergraduate students who choose to participate in actual laboratory research (Undergraduate Research Experience or URE) or courses with designed research experience (Course-based Undergraduate Research Experiences or CURE) and rarely include graduate students. According to Linn et al. (2015; see also Madan and Teitge 2013) those studies focus on learning outcomes by identifying the impact and benefits of URE and CURE rather than focusing on the learning process. Among the benefits and impact, those most often studied are retention and identity, understanding the nature of science and scientific practice, level of conceptual knowledge, and the impact of mentoring on students' future choices and attitudes (Frantz et al. 2006).

The majority of the reported studies are based on the pretest—treatment—posttest design, reflecting the comparisons of outcomes before and after participating in URE or CURE (see Linn et al. 2015). Additionally, assessments vary from retrospective surveys (~50% of 60 cases in Linn et al. 2015) through mixed methodologies (surveys and interviews) to interviews, study groups, and focus groups (Murdoch-Eaton et al. 2010). Only one study out of 60 has a core methodology that includes a qualitative method of direct observation (Linn et al. 2015). In CURE, the learning goal and learning outcomes are mostly well-defined, therefore surveys and knowledge/skills assessment may be sufficient to measure them. In URE, however, measuring outcomes of authentic research experiences depends on the specification of learning goals in a given laboratory context. For some of these goals, especially those pertaining to enculturation into scientific practice, cognitive-ethnographic methods of study are more justifiable. However, most of the existing studies, even those lending themselves to an ethnographic approach, often rely on surveys, test-based assessments, and grade-point averages (Slovacek et al. 2012).

As a consequence, the existing studies recognize what has been experienced and learned, but they fail to identify specific processes of learning. Moreover, studies based purely on surveys and test-based assessments offer only limited perspectives on enculturation processes into scientific communities that take place in research laboratories, especially if we consider the population of students who transition from undergraduate to graduate programs. On the other hand, the ethnographic approach to studying the impact and benefits of authentic research experiences creates an opportunity to do more direct and in-depth analysis of learning that takes place in the labs (cf. Linn et al. 2015).

It is also important to understand how research pedagogy is affected by long-term societal crises. The COVID-19 pandemic was severely disruptive to institutions of higher education. In the US, almost all universities halted on-campus instruction and research in the spring of 2020. According to the College Crisis Initiative at Davidson College, in fall 2021 only 27% of universities operated primarily in person, while 44% were fully online even through spring 2021. Online operation included every arm of colleges and universities, administration, education, and research. However, as education at universities transitioned to remote and hybrid models of instruction, faculty, staff, and students engaged in research could not return to their laboratory spaces to do research activities for over a year. In order to salvage any possibility of continuing their research and education mission, research laboratories had to adapt to the COVID-19 safety and risk mitigation requirements implemented by the universities, which stipulated that some of the lab research activities, like formal and informal lab meetings, had to be performed through online conferencing platforms. If the work absolutely demanded individuals to be in the lab, they had to take turns working alone, without their colleagues and mentors readily available to guide their research experience and learning.

As mentioned earlier, professional formation and training of future scientists and engineers are not limited to classrooms; rather, they take place while participating in authentic research experiences in working university research labs, and many, if not all, authentic research experiences depend on social interactions with peers, colleagues, and mentors. COVID-19 impacted such social interactions in the research lab and inevitably altered the process of the training and formation of research engineers. As researchers studying learning and formation of engineers in laboratory settings, we began to look at how this shift in response to COVID-19 changed the nature of these processes.

Science educators may wonder how our observations in engineering laboratories are related to science education at universities and in K-12 classrooms. The similarities in the scientific inquiry across the domains of science, engineering, and technology have been long recognized by leaders in STEM education, and systematic effort has been made to articulate them in science curricula. The Next Generation Science Standards (NGSS lead states, 2013), one of such efforts, emphasizes not only core disciplinary ideas but also science and engineering practices (e.g. planning and carrying out investigation), and cross-cutting concepts (e.g. stability and change or cause and effect). According to NGSS vision statement, emphasizing similarities between science and engineering will inspire students to pursue careers in science and engineering (National Research Council 2011). Our observations show that scientists and engineers alike are engaged in producing knowledge through similar practices of scientific inquiry across research laboratories in the institutions of higher education. As we have observed, engineers do not only engage in designing the solution to a current problem using existing technology. Often their research involves addressing complex challenges that require application of scientific inquiry practices such as formulating problems, planning, and carrying out investigations, designing experiments, analyzing data, and disseminating results. We believe that our observations in engineering research laboratories provide valuable examples of how scientific inquiry and engineering design practices unfold in real life and we hope that science educators and science students will find them inspiring.

In this chapter, we share our experiences with attempts to capture learning processes in two engineering labs during the COVID-19 pandemic. Two questions guided our inquiry: How does learning actually happen in authentic laboratory experiences? What are the effects of the COVID-19 pandemic on the learning process and authentic research experiences in the engineering labs? In the subsequent sections, we will briefly focus on the accounts of learning in the laboratory and on the processes closely tied to learning within pedagogies of engagement and authentic research experiences: self-regulation and feedback; we will then proceed to focus on the two engineering labs we observed and provide analysis of the kind of learning that unfolded before and during COVID-19.

12.1.1 Learning in the Laboratory

Our research project fits within the larger body of research in *laboratory studies* inaugurated by the work of Latour and Woolgar in *Laboratory Life* (1979/1986; see also Knorr Cetina 1995, 1999). This work adopts the attitude of "the anthropologist in the laboratory," that is, it presents the perspective of an ethnographic researcher who is totally naïve to the concepts and practices of science. Latour and Woolgar use this framing to examine the cultural practices of the laboratory, focusing on topics like the aims of the laboratory (to produce papers), the nature of laboratory equipment (inscription devices), the organization of the physical space, material resources, human activities within the laboratory, and most famously, the construction of scientific facts. The anthropological framing allows them to analyze these topics without short-circuiting their observations with descriptions based on the internal perspectives of scientists while ignoring social influences on the development of scientific knowledge. While they relax this pretense as the book goes on, in the second edition postscript, Latour and Woolgar famously eschew "far-fetched cognitive explanations over simpler social ones" (p. 274) and even propose a (probably tongue-in-cheek) "ten-year moratorium on cognitive explanations of science" (p. 280). From our perspective, the problematic assumption here is that social and cognitive explanations form a *dichotomy*, instead of considering the possibility that *social activities* realize or instantiate *cognitive processes* (Giere and Moffatt 2003).

More directly, our approach to studying authentic research experiences in engineering labs was inspired by the work of the Cognition and Learning in Interdisciplinary Cultures (CLIC) group at Georgia Tech, led by Nancy Nersessian and Wendy Newstetter. In their studies, CLIC uses a combination of ethnographic methods and cognitive-historical analysis of activities in a biomedical engineering research lab (Nersessian and Newstetter 2013; Newstetter et al. 2002, 2004). This particular combination of methodological tools allowed CLIC to demonstrate that a bioengineering lab is a constantly evolving distributed cognitive system, in which research and learning are intertwined and cannot be separated. Specifically, learning occurs as the interactions between lab members or between lab members and artifacts evolve, and this very same process contributes to research, resulting in conceptual and methodological knowledge distributed among lab members and artifacts (Nersessian 2006; 2009; 2019). In other words, in line with the critique of Latour and Woolgar above, the knowledge and cognition of the laboratory are realized through the social organization of the laboratory. When taking a close look at the interconnection and distribution of knowledge and cognition and the underlying social organization of the laboratory, Newstetter et al. (2004) observed that engineering research labs have a non-hierarchical organization in which no one person is *the* expert, that an interactional structure encourages participation and motivates participants, and that a strong social support system facilitates resiliency. Moreover, they also identified that the non-hierarchical organization of the engineering lab creates an environment conducive to *agentive* learning, in which learners interact with other agents of learning, including people and artifacts; are active, empowered, and motivated to seek learning opportunities and activities. In short, they see engineering research laboratories as sites of "robust and speedier learning."

Three implications from CLIC research informed our approach to studying the processes of the professional formation of engineers in a research laboratory. First the idea that an engineering research lab is an evolving cognitive distributed system led us to attempt to document short-term learning occurring at a given time and long-term learning unfolding over longer periods, and to analyze the distributed learning at the level of an entire lab, as well as at the level of an individual member. Second, the characteristics of an agentive learning environment gave us a framework to analyze the observed learning process and its interactions with the learning environment, and third, the emphasis on a strong social support system in an agentive learning environment led us to focus on socio-cultural networks in the observed engineering lab and their influence on individual lab members' learning and participation in research.

12.1.2 Learning, Self-regulation, and Feedback

The examples from the CLIC group show that learning within authentic research lab experiences empowers students, gives them agency over their learning processes and motivates them to build knowledge with others within the social and material learning space. Two aspects of such learning experiences are particularly important to us: self-regulation and feedback.

Self-regulation is essential to advance in any academic field, and cultivating self-regulated learners is one of the central goals in higher education (Hodges 2015). It is also a crucial element of the process of professionalization because in many workplaces, employees are expected to become responsible for their self-directed learning and training (Bell 2017; Cuyvers et al. 2020; Kittel et al. 2021; Smith and Curtis 2020).

Self-regulation is understood as an ability to monitor one's learning process and goals, to defer gratification, and to persevere in the face of difficulties. Self-regulation is linked to a set of beliefs about the quality of one's own knowledge and skills (self-efficacy) and to students' orientation toward achievement (mastery goals versus performance goals). Self-regulated learners are therefore aware of their knowledge, skills, beliefs, motivation, and cognitive processing and are capable of monitoring how well their cognitive engagement in learning matches their goals (Butler and Winne 1995; Van den Boom et al. 2007).

According to the evidence gathered by Zimmerman (2002; Zimmerman and Schunk 2001), self-regulatory and learning processes are intertwined in a cyclical way. At the onset of the learning process and during the *forethought* phase, learners' sense of self-efficacy and achievement orientation help define and set learning goals and the strategies to achieve them. As the learners get engaged in learning—the *performance* phase—the metacognitive aspects of learning, such as self-control and self-monitoring become evident. In the last phase of the self-regulatory process in learning, the *reflection* phase, the learners self-evaluate the results of their learning by reacting to them and by assigning causes to the learning outcomes that may or may not impact future learning strategies.

Completing a self-regulation cycle while learning depends on an individual learner's self-efficacy, achievement orientation, internal feedback, external feedback, and the interactions within and interconnectedness of a learning community (Hodges 2015). Butler and Winne (1995) point out that effective learners develop certain feedback routines while engaging with an academic task. For instance, learners may set a plan for working on a task, and such a plan, in turn, allows for generating criteria against which progress on a task is monitored. Students may modify their learning by readjusting present goals or setting new ones, and they may adapt existing skills or reevaluate and change learning strategies and decide upon more productive approaches. However, when a task at hand is too difficult or complex and its requirements exceed learners' current level of skills and knowledge, self-regulated learners actively seek feedback from external sources such as teachers' comments and peers' contributions in collaborative groups, and such external feedback often increases the effectiveness of learning.

As mentioned earlier, authentic research experiences in a research laboratory fall within the idea of pedagogies of engagement that seek to cultivate self-regulated and agentive learning. A research lab environment that supports agentive learning allows learners to interact freely with peers and mentors, and with artifacts, affording multiple opportunities for internal and external feedback. The emphasis in such an environment on empowering learners to stay motivated and to seek opportunities for their professional development affords the development of self-regulated learning.

12.2 Learning in Engineering Research Labs during the COVID-19 Pandemic

12.2.1 Cognitive Ethnography: Observing Learning as it Unfolds

Following CLIC's attempts to study learning processes in a biomedical engineering laboratory through cognitive ethnography, we implemented a similar methodological approach. Cognitive ethnography is a method aimed at investigating human cognition as expressed through cultural activity within real-world, "naturalistic" settings. It aims for understanding, explaining, or intervening in cognitive phenomena through detailed and refined analysis of ethnographic observation, digital photography, and video recordings. Hutchins argues for using cognitive ethnography to refine our understanding of how human cognition functions as "our folk and professional models of cognitive performance do not match what appears when cognition in the wild is examined carefully" (Hutchins 1995). Cognitive ethnography employs many of the same skills and practices as traditional ethnography, such as participant-observation, interviewing, and artifacts analysis. However, it combines them with the analytic techniques and theories derived from contemporary cognitive science. A central technique of cognitive ethnography consists of microanalysis of specific occurrences of events and practices to analyze in great detail the mechanisms and processes of interpersonal, naturally situated, and techno-socially distributed cognition (Alač and Hutchins 2004; Dubbels 2011; Hutchins and Palen 1997). To facilitate microanalysis, cognitive ethnography makes significant use of digital recording media and painstaking qualitative analysis of recordings (Williams 2006). Cognitive ethnography offers a powerful pathway towards understanding the functional specification of human cognition at both the individual and distributed scales; in other words, the functional role that cognition plays in relation to the environment, technology, society, culture, ongoing practices and activities, goals and problems, etc. Thus, cognitive ethnography is increasingly employed for studying cognitive activities that are environmentally and culturally situated (Lave 1988; Lave and Wenger 1991; Roth and Jornet 2013) and socially and technically distributed (Hutchins 1995 2014; Nersessian 2019; Nersessian and Newstetter 2013; Salomon 1993; Sutton 2006).

At the onset of our study on authentic research experience and learning in engineering labs, we used such traditional ethnographic tools as participant-observations, interviews, use of field notes, photos, and video-recordings. However, as the COVID-19 pandemic rendered our study impossible to continue, we decided to introduce an autoethnographic tool that our participant observer and our participants used to share accounts of their research and lab experiences.

Drawing from a cognitive ethnographic toolbox, we applied analytic frameworks from cognitive science, which enables fine-grained, micro-scale, and holistic analysis of cognitive activities that consist of discourses, nonverbal expressions, artifacts, and environment (Alač and Hutchins 2004; Grohman et al. 2020; Lee et al. 2015, 2017, 2020; Hutchins and Palen 1997; Williams, 2006).

12.2.1.1 What does a Participant Observer Do?

Our participant observer, one of the research team members, was embedded in the field site in January, 2020. The participant observer obtained access to a primary and a secondary laboratory and had a desk in the primary lab. She regularly visited the lab for hours at a time, observed the lab activities, asked questions, and took field notes. Occasionally, she conducted informal interviews. She also participated in a few lab activities. For example, she volunteered to be one of the subjects who tested a robot system, and she assisted to prepare another robot system for demonstration. When the COVID-19 pandemic hit, the participant observer had been collecting data in the field site for approximately two months.

At the beginning of the pandemic, all labs in the university were closed, and our field site was no exception. For a month, all research activities at the field site lab were halted. As all in-person data collection was prohibited, participant observation was no longer possible. After about a month, the lab members in the field site started holding lab meetings online, and we also began to observe these online meetings. The participant observer attended every lab meeting and conducted online interviews to collect data. The research team also obtained access to recordings for five of these meetings, and the lab members shared their research updates at the participant observer's request.

12.2.1.2 Participants as Observers: Collaborative Autoethnography

Participating in the lab meetings during COVID-19 lockdowns allowed us to collect some data, but without the benefits of participant observation. That is, we no longer could interact with the lab members in our field site by participating in their activities. On the other hand, the COVID-19 pandemic provided an unexpected opportunity to use an alternative ethnographic tool to interact with our participants, namely Collaborative Autoethnography (CAE; see Roy and Ueksa 2020 for a report on application in qualitative research). Collaborative Autoethnography is "(…) a qualitative research method that is simultaneously collaborative, autobiographical, and ethnographic (Chang et al. 2012)." It is based on self-reflection about an individual's experiences related to cultural, social, or physical circumstances. CAE also includes collaboration, allowing individuals to share and co-analyze their autoethnographic data to find meanings. By applying CAE in our study, we provided an opportunity for the participants and the participant observer to write and share their personal stories on the ways they coped with pandemic-related restrictions in relation to their research experiences. The CAE was also augmented by follow-up questions or interviews with the study participants.

12.2.2 *Two Research Labs*[1]*, Two Stories*

University research laboratories are typically independently run by their lead faculty. Departments and schools offer minimal oversight, and faculty are largely able to shape the practices and culture as they see fit. Often these practices and cultures are not formally or intentionally imposed, but arise organically from the faculty member's leadership style, their personality, and those of the researchers, etc. Thus, no two labs will ever be the same.

12.2.2.1 MHR Lab

Our primary field site was a mechanical engineering research lab at a state university in Texas. The primary research projects in the MHR Lab revolved around human-robot sensory interactions during medical intervention. At the onset of our study, the lab was of moderate size and included seven regular members: the lab director (a faculty member at the university), a postdoctoral researcher who recently joined the lab, and five graduate students. However, during the course of our observations, the MHR Lab underwent a few changes, some related to restrictions and lockdowns due to COVID-19, and some due to personnel changes. Specifically, during the early months of the COVID-19 pandemic, the lab was closed and some lab activities shifted to the online environment. When the most severe restrictions were lifted and the MHR lab reopened, the lab members had to follow strict limited-capacity guidelines, meaning that the lab members had to take turns working remotely or in the lab (only one lab member was allowed to be in the laboratory space at the time). As far as the personnel changes are concerned, during the course of our observation, one graduate student obtained her Ph.D. and became a postdoctoral researcher. However, the major event that coincided with our observation was the lab director's and lab members' relocation to another state university in Texas.

12.2.2.2 AP Lab

The AP Lab is at the same state university in Texas as MHR Lab originally was. It is a material science and engineering lab that focuses on advanced polymer research. The decision to add AP Lab as a secondary field site was dictated by the COVID-19 pandemic restrictions on in-person data collection and by limited opportunities to observe the labs as they operated in an online environment. With the MHR Lab relocation to another university, the AP Lab became our primary field site. At the beginning of the data collection, the AP Lab included approximately 16 lab members including the lab director, two postdoctoral researchers, and graduated students (some of them interns at local companies). Out of this group, eleven lab members—a postdoctoral

[1] The names of the labs are not acronyms but pseudonyms created by the participant observer. The lab directors' and lab members' names are pseudonyms as well.

researcher and ten graduate students—have consented to participate in our study and have been regularly attending online lab meetings. Similarly to the MHR Lab, the work at the AP Lab has been restricted due to the COVID-19 pandemic guidelines; the lab members have had to alternate their on-site shifts with remote work.

When comparing the field notes on the two labs, the methods of engagement by the lab director became clear, which are partially the result of the differences between the labs' sizes. In the MHR lab, medium size research laboratory, the lab's director was involved in organizing and leading the lab activities. In the AP lab, a much larger lab, the role of the organizer of lab activities, including the meetings, was assumed by a postdoctoral researcher.

12.2.3 The Impact of COVID-19 on the Research Labs

To uncover the ways the COVID-19 pandemic affected the authentic research experiences in the two field sites, we analyzed the data included in the participant observer's field notes, video recordings of the online lab meetings, interviews with the lab members, and the CAE stories written by the lab members. Specifically, we focused our analyses on those observed events that included various types of interactions among the lab members, such as peer discussions, teaching and learning exchanges, and collective problem-solving sessions. Examining those interactions allowed us to identify various roles lab members had in the identified events, emerging learning goals, and types of learning activities. As far as the CAE stories are concerned, we examined the emerging patterns of experiences related to the pandemic and its effects on the lab members' professional and personal lives.

12.2.3.1 Lab Meetings

Before the COVID-19 pandemic, the MHR and AP labs had a history of regularly scheduled lab meetings, during which the lab members (mostly graduate students) presented their research updates and received feedback from their peers and faculty. But once the COVID-19 related university lockdown forced the labs to shift their activities to virtual spaces, the new role of the lab meetings emerged, and different meeting styles of the MHR and AP labs became apparent.

When observing the MHR Lab online meetings, we noticed the friendly and relaxed atmosphere among the lab members. They usually kept their video feed on during the meetings and engaged in discussing various topics related and unrelated to the MHR Lab's research projects. For example, the lab members talked about selecting new furniture for the lab, discussed a mentoring session on writing peer-reviewed research papers, collaborated on writing a review paper, or presented updates on their individual research projects. The AP Lab meetings had a different style and resembled formal meetings, during which the lab members followed an agenda that focused on lab and research-related issues. The meetings included announcements of and updates on the AP Lab activities, discussions of lab safety issues, and student presentations. The formal character of the meetings was coupled with the lab members' preference to keep the video feed off, except for the postdoctoral researcher and mentor who led the meetings, and the lab member appointed to present their research update (the MHR and AP Labs meeting styles are summarized in Table 12.1).

With the different meeting styles emerging from the participant-observations of the online MHR and AP Labs meetings, we solicited the lab members' opinions about the meetings. The follow-up interviews revealed that people in both labs thought of the online meetings as a good opportunity to engage with one another professionally and socially. This was particularly significant to MHR and AP labs members when the university partially lifted the restrictions and the labs could reopen with limited capacity. During the limited-capacity operation, the lab members had to alternate shifts and could not share the physical lab space with other people, so even though some of the research-related activities took place in the physical lab space, the lab meetings remained the only occasion to virtually meet all of the lab members at the same time. The lab members admitted that attending the online lab meetings gave them the sense of security and belonging so much that the online lab meetings continued even after the university and lab activities were restored to full capacity and in-person mode. It appears that during the COVID-19 crisis, the regular online meetings were not only a venue for the research-related exchanges, but a new role as an anchor to hold the lab members together as a group also emerged.

Table 12.1 Comparison of online lab meetings in two field sites

Meeting characteristics	MHR Lab	AP Lab
Frequency and duration	Weekly, 1 h	Weekly, 1–1.5 h
Organizer	Lab Director (faculty)	Post-Doc Mentor
Participants	2 post-docs, 4 graduate students	10 graduate students
Video conference	Lab Director: on video All participants on video	Post-Doc Mentor: on video Participants: off video Presenter: on video
Topic to discuss	Various topics Decide what to discuss next at the end of the meeting	Fixed topics: Lab updates; Lab safety issues; Student research update presentation
Procedure	Varied according to the topic	(1) Lab announcement and updates (2) Lab safety discussion (3) Student Presentation (1 or 2)

12.2.3.2 Lab Members' Stories

Four members from the MHR Lab and seven members from the AP Lab shared written CAE stories. To analyze these stories, we developed an analytic framework based on Levine et al.'s (2021) study report that examined the impact of the COVID-19 pandemic on early career scholars and doctoral students in the education area. Adjusted to the unique background and circumstances of graduate students in engineering, our analytic framework included the following themes that emerged from the key terms the labs members used in their stories: background, impacts on research, continuing research work, learning, connections/community/communication, and work-life balance. Each story was carefully analyzed based on these themes, and the general profile for each theme was extracted. The following examples are excerpts from the CAE stories written by the MHR and AP lab members. The findings are summarized in Table 12.2.

The analysis of the emerging themes in the written CAE stories suggests that the members in our participating labs were trying to continue research activities as best they could during the COVID-19 pandemic and the related lockdowns. The *Background* theme indicates that at the onset of the university lockdown, the MHR and AP Labs members were mostly planning or preparing for a new research project, graduation, or internship. As the COVID-19 pandemic effectively stopped them in their tracks, the lab members experienced and shared negative impacts of the pandemic on their research activities that were now *delayed*, *slowed*, or had *suffered in efficiency* (see Table 12.2). Despite the difficulties the lab members encountered, they tried to continue their research and learning or shift to alternative activities and remain productive or beneficial in a wider sense, such as joining an expert group to help health workers.

The themes related to continuing research work allowed us to notice an interesting difference between the MHR and AP labs, perhaps based on their areas of expertise (see Table 12.2). The MHR Lab focuses on human-robot interaction and their research protocols involve human subjects. Thus, when in-person data collection was suspended, the MHR lab members, either shifted their research activities to nonhuman subject studies such as virtual simulation or used their time to revisit and reevaluate previous data analyses. While shifting the focus of research activities away from in-person data collection, the MHR lab members continued to work remotely. In contrast, the area of expertise among the AP Lab members is in material science and does not require interactions with human subjects. Therefore, many AP Lab members tried to go back to the lab by obtaining permission to do so or by adhering to the limited-capacity guidelines (e.g., social distancing, taking turns to work in the lab alone). For example, one lab member took night shifts to work in the lab and, consequently, they did not see any of the fellow lab members for months! Apart from seeking ways to continue work in the laboratory space, quite a few AP Lab members joined a local expert group to develop innovative personal protective equipment (specifically masks) to help frontline healthcare workers. This way, not only did they continue their engagement in authentic research experiences, but they also made a contribution with their expertise in material science.

Table 12.2 Key themes and key words in the lab members' CAE narratives with examples

Key themes	Key words		Examples
MHR/AP Labs	MHR Lab	AP Lab	MHR/AP Labs
Background	Start, prepare	Plan, graduate, prepare	*"Things were going well and I was just about to get started on human studies for the sleeve* [surgical tactile device—MG]. *when the Covid-19 situation started"* (Rob, post-doc, MHR Lab)
Impacts on research	Difficult to manage, suffered in efficiency, no human studies	Affected my (plan, graduation, work pace), delayed, slowed	*"(…) by the end of May, I started to notice a little slow down in my activities. This* [new] *routine began to affect my work pace"* (Oliver, Ph.D. student, AP Lab)
Continuing research work	Shifting, revisiting, reevaluating	Joined (expertise group to help, a new group to continue), get back to lab (with special permission, with limited capacity)	*"I decided to change my thesis topic again, to try making better facemasks (…) to at least try to do something"* (Brad, AP Lab)
Learning	Learning, practicing	Learning (a new way, software, etc.), reading and reviewing papers	*"I had reached a point in my research that allowed me to focus on data analysis and paper writing, so I wasn't worried about continuing my research"* (Rob, post-doc, MHR Lab)

(continued)

Table 12.2 (continued)

Key themes	Key words		Examples
MHR/AP Labs	MHR Lab	AP Lab	MHR/AP Labs
Connection-community-communication	Same communication in professional life	Keep us accountable, keep in touch	*"I miss to have the opportunity to practice my presentations in person but I believe that having the opportunity to keep in touch with the lab members has been good for all the group members, especially for those who live alone"* (Caro, Ph.D. candidate, AP Lab)
Work-life balance	Challenges in home environment, use the commuting time for something else	Not working very well (with two small kids), not that bad (used time for personal growth)	*"(…) working from home has its challenges. I live in a one-bedroom apartment, which I share with my wife, two cats and a dog, and I now* [wish] *that we had gone with a two-bedroom unit, so that I could be working from an office of sorts, instead of a table in my living room".* (Rob, post-doc, MHR Lab)

The analysis of the theme related to personal circumstances and work-life balance revealed yet another difference among the lab members. For example, two members of the AP Lab expressed different feelings about balancing professional and personal life during the pandemic. A member who was a parent with two small kids mentioned "not working well" and feeling "exhausted," while another member who lived alone mentioned, that balancing professional and personal life was "not that bad" because he could use the time for personal growth (see Table 12.2).

12.2.4 Emergent Learning Processes in the Research Labs

12.2.4.1 Self-regulated Learning as the Default Learning Strategy

Based on our observations and analyses of in-person and online interactions between the lab members in the MHR and AP Labs, we propose that the learning in the engineering research labs is agentive and self-regulated (Hodges 2015; Nersessian and Newstetter 2013; Newstetter et al. 2002, 2004; Zimmerman 1990; Zimmerman and Schunk 2001), and as such indicates that learners take control of their own learning process and remain motivated and empowered to conceptualize, design, and execute learning tasks related to their research activities. The members of the MHR and AP Labs each had their own research project to conduct. While they could seek guidance or help from their advising faculty or more experienced peers to choose their topic, plan the research procedure, or to solve any emerging problems, the decisions were their own to make.

As illustrated in the cultural model of MHR and AP lab members' self-regulated learning processes (Figure 12.1), the lab members chose what they wanted to learn and made plans about how to proceed. They controlled the procedure and revised or altered it as needed. These self-regulated learning processes were closely related to the individual lab members' research projects and were still clearly observable when the lab members were meeting online during the COVID-19 pandemic. As indicated in the analysis of the CAE stories, to adjust to the pandemic-related restrictions, the lab members actively sought alternative ways to continue their research. Some switched their research topic to a topic that they could do at home. If possible, they took all the devices and resources home and continued to work, or where it was not possible to continue their initial research projects, they participated in alternative projects, such as using their expertise to combat the pandemic.

12.2.5 Feedback and Scaffolding as Organic Instructional Strategy

Self-regulated learners actively seek feedback from external sources (e.g., teachers' and peers' comments) and, in turn, the external feedback enhances self-regulated learning (Butler and Winne 1995). During the observation of the MHR Lab, we noticed that the lab director—who was also an advising faculty to graduate students—provided feedback that helped to guide self-regulated learning in the lab. Namely, the lab director differentiated her feedback according to the current level of skills and abilities of the student who presented their work during the lab meetings. When the presenter was experienced and familiar with the topic, the lab director asked questions or made comments that tend to trigger more discussion about the content of the presentation such as "Have you tried ...?" and "One idea I have about this is …". Thus, the exchange between the lab director and the more experienced student resembled

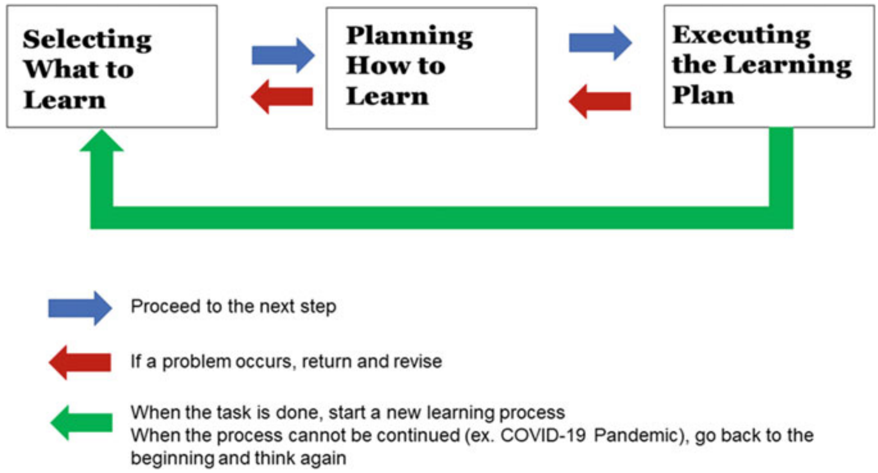

Fig. 12.1. The cultural model of self-regulated learning process that occurs in the engineering lab

discussions between professionals at an academic conference. However, when the presenter was less experienced, or the topic was unfamiliar to the presenter, the lab director often provided additional explanations—"Let me explain…"—or brought up related knowledge—"Do you remember ...?" In contrast to the quasi-professional exchanges described above, the back and forth here resembled interactive teaching approaches in the classroom.

The way the lab director used feedback during the student presentations (i.e., considering students' skills, knowledge, and experience) reminded us of the pedagogical strategy known as "scaffolding" (Grohman et al., in preparation). In general, scaffolding is a strategy in which an expert provides the necessary support for a learner to accomplish a specific task, and this support is differentiated according to the learner's ability and situation. As the learner obtains more independence, the expert's support is gradually diminished (Malero et al. 2012; Sharma and Hannafin 2007; Wood et al. 1976).

In most educational settings, scaffolding is used as an intentional or overt instructional strategy to guide the learning process (Malero et al. 2012). Interestingly, the lab director was not aware that she was using scaffolding as an instructional strategy, as shown in the following excerpt from her email correspondence:

> I'm not aware that I'm doing it, but I do try to make sure that if a student brings something up that only the two of us are familiar with, I try to give that context to the group. Also, as students get more experienced, I try to encourage them to act more independently since that is my long-term goal for their education (Dr. Mac, the director of the MHR Lab).

As can be seen in the excerpt, scaffolding used in the MHR Lab occurs without formal planning or instructional design. We call this type of instructional strategy an *organically-occurring scaffolding*. We discuss more details about scaffolding in the engineering lab in a separate publication.

12.3 Implications for Professionalization and Learning in Research Labs during Crises

What are the larger implications for professionalization and education during a crisis like the COVID-19 pandemic? First, it is important and hopefully not too obvious to say: students do not stop learning in a pandemic lockdown, despite the incredible disruptions to routine. Under those conditions, labs had to develop new mechanisms for supporting learning mechanisms such as self-regulation and feedback. In particular, we noted that self-regulation became a more significant factor than it might be under normal conditions. It is not a stretch to hypothesize that prior preparation for self-regulatory learning might be an advantage in many disruptive scenarios, giving students with such skills greater resilience.

Regular laboratory meetings became a forum for both professional and social support. Under pre-pandemic circumstances, students received social support inside and outside the laboratory through their everyday interactions with colleagues and friends. Such casual interactions were limited for all of us who were engaged in some form of sheltering or isolation during the pandemic. In the laboratory in particular, casual interaction almost entirely ceased. The two laboratories we observed reacted very differently to these changes. Lab meetings under pre-pandemic conditions typically had a more or less formal structure that helped them to efficiently serve their function of exchanging information, planning, and learning. The AP lab retained the basic structure and tenor of those meetings during the pandemic.

The MHR lab, on the other hand, adopted a less formal, more "friendly" approach, and in so doing became a major forum of social support for the members. This seems to have led to a more fluid transition for the MHR lab to shifting work focus and addressing the problems at hand. There was greater engagement of the members in the meetings, including most members having their cameras on, and explicit provision of social support. Through these meetings, the MHR lab provided a social support network for its members that eased the difficulties created by the pandemic response.

The COVID-19 pandemic gave us a rare opportunity to observe how student learning, professionalization, and research experience are constrained by their individual circumstances. Learning occurs in contexts that go beyond the university classroom and the laboratory. It is difficult to overstate the importance of this insight; educators often wrongly understand student learning as entirely a function of their performance in classroom and laboratory activities. But the students' educational and professional goals and outcomes are in fact intertwined with their private lives and the resources they have at hand. In this case, social support from lab mates, work from home arrangements, and availability of material resources at home, all had important impacts on the students' learning and professionalization.

A key insight of distributed cognition theory (Hutchins 1995) is that social relations, social organization, material artifacts, and social and communicative acts can be not only *about* cognitive matters; they can *be* cognition. Nevertheless, for most of us, under most conditions, the *social* meaning of our relationships, organizational structures, words, and actions are most salient. For Hutchins, this is merely a reflection of our evolved capacity as social creatures; as he says, “If it is true that human minds evolved to process social relations, then packaging a task in a social organization may facilitate understanding it” (1995, p. 263). The cognitive activities of learning and knowledge-creation are packaged in the social organization of the laboratory; those activities will be disrupted if the laboratory no longer can support the social relationships and meanings it previously provided. “Social moves have [cognitive] as well as social consequences. [Cognitive] moves have social as well as [cognitive] consequences” (ibid.).[2]

12.4 Note to Our Future Colleagues

Greetings from your colleagues in the academic year 2021-22. We are currently in, what we hope is, the tail end of the COVID-19 pandemic. Hopefully, it recedes in the next year or so, and life—including university education and research—becomes similar to what it was prior to the pandemic. However, we recognize that this could be much more drawn out, and that COVID-19 could linger for years, with potential future outbreaks. Over the next 30 years, it seems a near certainty that there will be other severely disruptive events. For example, we already see extreme weather events forcing closures and evacuations for a week or more at a time. Climate change will likely exacerbate this and lead to other problems. We believe that our study offers invaluable insights into how to guide learning and professionalization in research laboratories during disruptive and adverse events.

In our research during the COVID-19 pandemic, we recognized the resilience and drive of researchers at all levels. From senior faculty to undergraduates, research finds its way to thrive. The two labs we observed pursued different strategies to continue their work, as befit their research focus, the experience of their members, and size. What the students across AP and MHR labs had in common was a notable level of self-regulation of their own learning, including the ability to adapt to changing circumstances in their professional and personal lives. This self-regulated learning was accompanied by feedback from senior lab members and directors adjusted to the learners’ research experiences and their personal contexts. This plasticity in self-regulation and feedback may be a necessary component of robust research labs during uncertain times.

Another common characteristic in the two labs was a need to maintain a social “safety net” through building and cultivating collegial relationships with the lab members. The social cohesion was facilitated by videoconferencing tools, which are now quickly becoming a “new normal” method of formal research and education, even as universities and other workplaces ease restrictions on in-person attendance.

[2] In the original text, Hutchins says “Computational” instead of “cognitive”—in the book he relies on the then-standard computational-representational understanding of “cognition” and moves easily between the two, in a way that we might be less comfortable with today.

We predict that this trend will continue over the next 30 years. Many companies are already experimenting with permanently remote workers.

The ability to conduct research remotely, at the level of a Master's thesis or Ph.D. dissertation, has not been well-explored. It now seems feasible that graduate research degrees could be awarded through purely remote access, or through a mixture of remote and in-person work in the lab. This can allow work to continue during future disruptions and open the way to graduate STEM education to students who would previously not be able to pursue an advanced degree due to difficulties in the residential requirements of graduate education. One issue that is clear to us, is the need to foster the spirit of collegiality within the lab. Lab members will continue to need social outlets and interactions, even if just during weekly meetings, and research laboratories will require leadership invested in encouraging and maintaining a productive and collegial atmosphere among their students, staff, and colleagues. The material and social environment of classrooms and laboratories cannot be ignored as we design future learning, professionalization, and work environments and processes.

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