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Work in Progress: Student Learning Experiences in the Research Lab: Qualitative Analysis of Two Types of Leadership-Mentorship Style

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Abstract
Multiple studies report the benefits of authentic research experiences in STEM education. While most of them focus either on course-based research projects or on undergraduate students' experiences, few document authentic learning experiences unfolding in real time among and between graduate students in research laboratories. Therefore, we situate our study in the context of authentic research experiences in research laboratories and focus on documenting learning processes as they unfold during daily practices in the laboratories. Specifically, the goal of our study is to observe and document how graduate students, and other lab members, learn from one another within the cultural space of the laboratory, and what aspects of laboratory culture facilitate and what impede learning. To that end, we use cognitive ethnography, an ethnographic approach combined with cognitive science to study cognitive processes through participant-observation of two engineering research laboratories. We identified the following themes pertaining to learning experiences: scaffolding (structured activities or apprenticeship), peer-to-peer learning, self-directed and self-regulated learning, and independence in research activities. While in many respects the two laboratories are similar, the presence and role of a leader-mentor in daily activities is what set them apart. In this report, we analyze the impact of leadership-mentorship on learning and professional formation. We argue that the degree to which a leader-mentor is consistently active in the laboratory's life presents advantages and disadvantages with respect to different aspects of learning and professional formation. On one hand, professional development of students may be hindered by the absence of direct oversight from an in-laboratory professional mentor, resulting in delayed graduation for example. On another, absence of direct oversight can compel students to independently seek out mentors who have important expertise to help complete projects in a timely manner, an important professional skill. In the first case, students benefit from the expertise of mentors, so having mentors consistently present in the laboratory helps students efficiently conduct their projects. In the second case, students learn that they cannot always rely on only one person to provide direction and will need to seek help from other quarters.

Introduction

We report here part of a four-year study of the formation of engineers in the research lab that explores how learning unfolds in the context of authentic research experiences, where students are actively involved in research projects. We use a cognitive-ethnographic approach study learning processes as they unfold during daily practices in research laboratories. We aim to understand how lab members learn from one another within the cultural space of the laboratory, which aspects of laboratory culture facilitate and impede learning. In this report, we focus on two themes: how lab members learn from one another, and the role mentors play in the learning process. Data collection and analysis are still ongoing, hence these are preliminary results. To provide a framework for our analyses, we offer a succinct review of research on authentic research experiences, on learning in laboratories, and on leadership and mentorship in laboratories.

Authentic research experiences

Authentic research experiences (AREs) are understood in terms of student participation in traditional laboratory or field research overseen by a faculty member, as well as courses that reproduce or simulate the actual processes of scientific research. They are understood in contrast with "cookbook experiments" often performed in lab classes [1]. AREs are recommended as a model of how STEM students should learn; however, these recommendations have not received the rigorous examination they deserve, given their increasing prominence in engineering pedagogy. AREs could be considered exemplars of situated learning and, in principle, should lead to deep learning of the principles and practices of STEM research [2], [3]. The value of such experiences is widely assumed, and this assumption is behind programs like the National Science Foundation (NSF) funding stream for Research Experience for Undergraduates (REU).

Previous investigations of research experiences tend to focus on undergraduate students participating in actual laboratory research (Undergraduate Research Experience or URE) or courses with designed research simulations (Course-based Undergraduate Research Experiences or CURE). These studies rarely explore the experiences of graduate students. Furthermore, this body of research largely emphasizes learning *outcomes* of URE and CURE – how do they affect the sense of professional identity and persistence in programs, knowledge of research practices, conceptual understanding of the subject matter communicating the nature of science, etc. – rather than trying to understand the *learning processes* that lead to these outcomes [4], [5].

CURE, as a course-based experience with pre-defined learning outcomes, is very amenable to outcomes-focused research using surveys, test-based assessments, and grade-point averages [6]. However, URE does not have the same kind of set learning goals; the primary goals of the URE context are the knowledge-production goals of the working laboratory. Learning here will, of course, be a more organic by-product of the enculturation of students into scientific (and engineering) practice. Graduate research experiences are akin to URE in terms of difficulty to assess learning outcomes. Rather than focusing on outcomes defined from the start, we use *cognitive-ethnographic methods* to understand the social learning processes at work and immanent pedagogical aims and outcomes in laboratory practice. The feasibility of this approach is demonstrated by a significant body of related work in cognitive ethnography [7], [8], situated learning [9], [10], laboratory studies [11]–[15], and related approaches [16], [17].

Learning in the laboratory
Situated learning theory posits that “knowledge, thinking, and the context for learning are inextricably tied and situated in practice” [18]. Research laboratories provide a learner-centered context wherein learners construct meanings while engaging in authentic activities [18]. Learning in such contexts can be seen as a product of intricate interactions between lab members or between lab members and artifacts central to their work [19]–[21]. As such, learning in a research laboratory is *situated* within a culturally structured setting where learners (lab members) are understood as actors who work with physical and conceptual tools in concert with others. From the perspective of *situated learning*, internalizing knowledge is no longer a learner’s main goal. Instead, skillful participation in a group practice, the capacities of the group, and the outcome of the practice become the main learning objectives. In other words, it is not the learner's internalized knowledge that matters, but their capacity in situationally-specific, goal-directed, real-world activities to solve problems necessary to further their learning goals.
In their Cognition and Learning in Interdisciplinary Cultures (CLIC) research project, Nersessian and Newsletter use a cognitive-ethnographic approach to study a biomedical engineering research lab [22]–[24]. Nersessian et al. studied how the lab members—as situated learners—coevolved with the distributed cognitive system of the laboratory. As a cognitive system, the lab learns how to produce empirical knowledge on one hand, and how to improve its knowledge-producing practices on the other hand. The lab members, situated within that system, learn how to skillfully participate in the knowledge-producing distributed cognitive activities [19]–[21]. Nersessian and Newsletter [23] have also demonstrated that engineering research laboratories create an environment that empowers robust and fast *agentive* learning through non-hierarchical organization and an interactional structure that facilitates engagement, motivation, social support, and resiliency.

Leadership and mentorship in research laboratories
Traditionally, leadership has been understood as a set of skills or characteristics leaders use to directly influence followers and motivate them to take action that results in achieving goals. It often is regarded as a centralized form of control, where one individual exerts power and influence upon others [24]. However, recent theoretical approaches propose that leadership is framed as an alignment of the leader’s and group members’ values, attitudes, and motivations. This alignment motivates group members to act and fulfill the leader’s goals [24]. By making their values salient, leaders activate those aspects of their self-concepts (identities, beliefs, attitudes) to which their followers can relate. By creating the relatedness of the self-concepts, leaders and followers form a collective identity that then aids in motivating and regulating the followers’ behavior [24].

Complexity Leadership Theory, another non-traditional approach to leadership, argues for leadership seen as a “system of dynamic, unpredictable agents that interact with each other in complex feedback networks” [25]. Leadership that emerges from such complex systems can focus on adaptation (producing change, knowledge dissemination, learning, and innovation), administration (producing formalized plans of action), or enabling (minimizing constraints of bureaucracy) [26]. A similar understanding of leadership—not as localized in any one individual but as distributed between agents—is the view of shared leadership [27].

In research laboratories, the form the leadership takes—traditional and centralized or distributed and emergent—depends on the organizational structure and social arrangements of a lab (understood as a group of people sharing a common space and research agenda). The ethnographic study of bioengineering labs mentioned above [28] noted that the formal leaders—the Principal Investigators (PIs)—were charged with higher-level tasks aiming at maintaining the integrity of the lab for its members and the world outside, such as formulating and representing the research agenda of their labs, securing funding, attracting students to the lab, advising, and supervision and oversight of their labs' research activities [28]. On its face value, the position of the PIs as formal leaders and supervisors suggests that their influence and control are centralized and that their role is to influence and motivate their labs to achieve the PIs' goals. However, a closer look at ethnographic studies of research laboratories points to a far more complex picture. While it seems justified to view PIs as "traditional" leaders in their role of overarching supervision, the tasks related to advising and mentorship are often shared and distributed among other lab members. For example, a longitudinal study of 336 Ph.D. students' trajectories of skill development demonstrated that mentorship that had a significant effect on Ph.D. students' learning was not solely in the hands of PIs but was distributed among the PIs and senior laboratory members in a cascading fashion, with postdocs playing a significant intermediary role [29].

Research questions

We are guided by two primary research questions: 1) What is the role of peer-to-peer learning in research laboratories, and how do lab members learn from one another? 2) What role do mentors play in the learning processes in the lab, and how does this role change depend on the leadership style and level of the mentor?

Methods

Cognitive ethnography

Cognitive ethnography is a method for investigating human cognition as expressed through cultural activity within real-world settings. It aims to understand, explain, or intervene 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" [7]. Cognitive ethnography employs many of the same skills and practices as traditional ethnography, such as participant-observation, interviewing, and artifact analysis. Participant-observation is a central method in most field studies; it requires the observer to interact with participants in the field site in order to gain familiarity with their activities and build rapport with the research participants. It is a mistake, sometimes made by scholars unfamiliar with field studies, to think that interaction between observer and observed must be minimized to avoid confounds and increase objectivity. Active participant-observation actually tends to decrease participant reactivity to being observed as compared to "pure" observation, allowing the participant-observer to observe more natural behavior and activities that might be hidden from outsiders. It tends to improve both the quality of data and the quality of the interpretations of that data. Participant-observers must maintain critical reflexivity to monitor the potential impact of their interactions on the activities observed [30].

Cognitive ethnography combines the techniques of traditional ethnography with the analytic techniques and theories derived from contemporary cognitive science. A central technique of cognitive ethnography consists of microanalysis of specific events and instances of practice to gain a detailed understanding of the mechanisms and processes of interpersonal, naturally situated, and techno-socially distributed cognition [31]–[33] To facilitate microanalysis, cognitive ethnography makes significant use of digital recording media and fine-grained qualitative analysis of recordings [8]. Cognitive ethnography offers a 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 [9], [10], [34] and socially and technically distributed [7], [21], [22], [35], [36].

Field sites

Like most university research laboratories, the two laboratories that participate in our study are independently run by their PIs, with minimal oversight from departments and schools. The PIs are largely able to shape the practices and culture of their labs 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. The description of the laboratories includes references to the labs' research agendas, their socio-cultural space, and the physical space the labs occupy [31]. Please note, that for confidentiality reasons, the gender identification of the participants in our study will not be disclosed. In both observed laboratories, the membership was small enough to easily identify participants by referring to their gender.

<u>Mechanical Hand Research Lab</u>

Mechanical Hand Research Lab (MHL) was a mechanical research laboratory at a state university in Texas. The lab's research agenda focused on human-robot sensory interactions in medical intervention. The lab had been collaborating with surgeons and researchers in the local hospital and the medical school. At the time of the observations, from January 2020 through August 2021, the MHR Lab was of moderate size and had between 10 and 7 active members. At the beginning of our participant-observation, the PI oversaw one postdoc researcher, who recently joined the lab, five graduate students, and three undergraduate students. Because undergraduate students come and go each semester, the number of undergraduate students in the lab varied during the observational period.

During the participant-observation period, the MHR lab occupied three spaces in a four-story engineering building on campus: an office shared with members of several other labs, the main laboratory on the second floor, and the secondary laboratory shared with another lab on the third floor. Because the main laboratory of the MHR Lab was located on the same floor as the office space, the lab members often went back and forth between the spaces, with some spending most of their time in the main laboratory and others—in the office space at their desks. The secondary laboratory on the third floor was shared with another lab and was rarely used. For the meetings and discussions, the MHR lab used one of the conference rooms available in the building. Access to the MHR office and laboratory and the organization of workspaces was different for the graduate and undergraduate lab members. The graduate students had access to the office and the main laboratory, and the undergraduate students had access only to the main laboratory. The post-doc and the graduate students had their desks in both spaces, but the undergraduate students had their assigned desks at the main laboratory.

Advanced Polymers Research Lab

The Advanced Polymers Research Lab (AP) is at the same state university in Texas as MHR Lab originally was. In October 2020, the decision was made to add AP Lab as a secondary field site. It 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. However, with the MHR Lab relocation to another university, in October 2021 the AP Lab became our primary field site. The participant-observations in the AP Lab are ongoing.

The AP Lab is a material science and engineering lab whose research agenda revolves around the development of new polymers and the fabrication of microelectronic implantable devices. At the beginning of the data collection, the AP Lab included approximately 17 lab members including the PI, lab director (a postdoc researcher, marked with PDM in subsequent analysis), two postdoctoral researchers, and graduated students (some of them interns at local companies). Out of this group, eleven lab members—a lab director and ten graduate students—consented to participate in our study. These members were regularly attending online lab meetings during the COVID-19 pandemic, and they resumed their activities in the laboratory once the restrictions were lifted. During the participant-observation, the number of active lab members decreased to eight. Just like the MHR Lab, the AP Lab experienced personnel changes. In the early summer of 2021, the postdoc and lab director left the AP Lab; between December 2021 and October 2022, two graduate students obtained their Ph.D. and left the lab: NM1, whose research was in the area of recyclable polymers, and NM2 who specialized in new biodegradable materials for PPE. Before the NM1 and NM2 graduated, the participant-observer interviewed them about their research and learning experiences.

Currently, the AP Lab includes the PI, 6 graduate students, one undergraduate student, and one graduate student affiliated with another local state university but now collaborating with the AP Lab in the area of microelectronic devices. Out of those 7 graduate students, one works in the area of polymer development (NM3), one in material sciences and microelectronic devices (NMD1), and four (NND1, NND2, NND3, and NND4) have projects on implantable neuronal microelectronic devices. In terms of graduate research experience, six have already presented their dissertation proposals, with one working on their dissertation (NND1), and four (NM3, NMD, NND2, and NND3) conducting experiments and collecting data. One student (NND4) works on their dissertation proposal (see Table 1. for study participants codes summary).

Table 1. AP Lab study participants' code names and description, and lab member affiliation status at the time of observation.

Code Name	Code Name Description	Affiliation/Status
PDM	Postdoc Mentor	No longer with AP lab
NM1	New Materials graduate student 1	Graduated
NM2	New Materials graduate student 2	Graduated
NM3	New Materials graduate student 3	Current student, dissertation proposal accepted
NND1	New Neuro-devices graduate student 1	Current student, dissertation defense scheduled
NND2	New Neuro-devices graduate student 2	Current student, dissertation proposal accepted
NND3	New Neuro-devices graduate student 3	Current student, dissertation proposal accepted
NND4	New Neuro-devices graduate student 4	Current student, scheduled to present dissertation proposal
NMD1	New Materials and neuro-devices 1	Current student, dissertation proposal accepted

Note. Codenames have been assigned based on the area of study (e. g. Neuro-devices) and seniority level of the AP lab members denoted by the consecutive numbers in the code names, where 1 = most senior/advanced and 4=least senior/advanced.

The AP Lab is in a biological science building that is shared with many other research laboratories. The AP Lab members perform their research activities in the following spaces. The chemistry lab ("Wet Lab") is a shared space between multiple material sciences labs, where the AP Lab members have 4 designated hoods, shelving with chemicals, and work benches. The Wet Lab is used mostly for the preparation of materials such as polymers, coating substances, and the like. Next to the Wet Lab is the "3D Print Room", where the printing properties of some of the polymers are tested. Adjacent to the Wet Lab is the "Testing Lab." This space is used primarily to set up measuring equipment to test the conductivity of some of the microdevices. The students work also in the laboratory space located in a separate building. The space is called the "Clean Room" and it contains equipment necessary to fabricate microdevices. This space is shared by multiple research labs. Access to the Clean Room is restricted and only those who have undergone training can book the equipment and be granted access.

On both sides of the enclosed space with the Wet Lab, the Testing Room, and the 3D Print Room are the cubicles for the students and separate rooms for the PIs and senior research personnel from various labs. The AP Lab members occupy the cubicles on one side of the enclosed space. Because they sit close to one another, they tend to discuss their work while at their desks. Their diverse backgrounds also contribute to the spontaneous discussions, because whenever one of the members faces a problem, they can always rely on a person who has expertise related to that problem.

Data collection

In January 2020, at the start of the data collection, our research team included the PI, two co-PIs, and the research associate. The research associate was the participant-observer between January 2020 and early August 2021. She started the in-person observations at the MHR Lab and continued them until March 2020, when due to the COVID-19 pandemic all activities and the university were closed. Our research team then decided to switch from in-person observations to online observations and use elements of autoethnography in the online observations. Due to the limited nature of online observations, in October 2020, we added the secondary study field—the AP Lab. Thus, the participant-observer was now documenting online meetings and discussions in two field sites. The online participant-observations continued through July 2021. In August 2021, the research associate left the university and our research team. One of the co-PIs, who was at the same university as the PI and the AP Lab, was designated to resume the in-person observations of the AP Lab.

Positionality of the participant-observers

The two field sites in our study were observed by two participant-observers (PO1 at MHR and AP Lab, and PO2 at AP Lab). Both PO1 and PO2 shared demographic and experiential characteristics that enabled them to fit in as participant-observers. The observers were researchers and had extensive knowledge about and practice with the process of scientific inquiry. In their early careers, both immigrated to US to continue their postdoctoral studies; both became parents while learning the research craft in their respective disciplines, and both remembered the hardship of graduate studies. These experiences, as immigrants, as researchers, as parents with young children, as former postdocs, and graduate students, helped the observers with building rapport and creating bonds with the labs' members who shared similar experiences. During many spontaneous discussions about the graduate work, relationships with supervisors, parenthood, and "the pain of writing dissertations", PO2 often shared her knowledge, experiences, and insights, and wherever appropriate, offered her emotional support to the AP Lab members. Finally, both PO1 and PO2, engaged with their respective field sites in the daily lab activities, such testing equipment (PO1) or sorting and reshelving chemicals and cleaning the Wet Lab (PO2).[1] Below, we describe the methods of data collection employed by both PO1 and PO2 at their respective field sites.

Participant-observation in the MHR Lab

PO1 visited the MHR Lab three to five times a week and spent two to three hours at the lab every time she visited. PO1 had access to the main and supplemental laboratory spaces and had her desk at the main laboratory. Although she did not have access to the shared office space she could go there if needed, either by making an appointment or with someone who had access credentials. PO1 spent most of her time at the main laboratory, the space where the MHR lab members mostly interacted with each other, taking field notes on her daily experiences in the lab and any activities and interactions she observed. These notes include short conversations between the lab members, hour-long lab meetings, one of the lab member's experiments to test a robot, and the observer's experience with participating in robot-testing experiment. She occasionally took pictures of the activity or of the artifact. While observing lab activities, PO1 asked the lab members questions about the observed activity and the expertise it involved. At times, PO1 also participated in the lab members' research. For example, when one of the lab members needed to pilot-test the daVinci Research Kit (dVRK), robotic arms that surgeons use in precise teleoperated surgery, he asked for volunteers from among the lab members. PO1 volunteered along with the post-doc and an undergraduate student and tried dVRK. In addition to observation and participation, PO1 also conducted informal interviews with the lab members, as well as attended weekly lab meetings.

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[1] These types of rapport-building interactions and participation in daily activities are typical features of participant-observation, the standard approach to qualitative field studies not only in cognitive ethnography, but also in most parts of anthropology and sociology. See above under "Methods, Cognitive Ethnography." These interactions improve the quality of the observational data and the ability of the researchers to interpret that data.

Virtual participant-observation in the MHR Lab

The COVID-19 pandemic disrupted the functioning of the university in a significant way. Teaching, learning, and research activities on campus, including our participant-observation, stopped; access to the buildings became severely restricted, and the university largely shut down. It took a month for the MHR Lab members to determine how they could continue their research. Eventually, the lab members reorganized their research activities and priorities to adjust to the new situation. Those who worked on portable devices took them home to continue research remotely, while the lab members who before COVID-19 had used large or dangerous equipment, changed their research focus from data collection to coding and simulation or writing a research paper. The weekly lab meetings, advising and discussions were moved to a virtual space. To follow the online activities, PO1 joined the virtual weekly meetings and activities. The interviews were also conducted via MS Teams and main communication regarding observed activities was now maintained via email. PO1 continued to take field notes, archived email exchanges, and video-recorded online interviews.

Participant-observation in the AP Lab

Between November 2021 and May 2022 and then between September 2022 and December 2022, PO2 visited the AP Lab at least two times a week. Each visit lasted from two to four hours. PO2 had access to the space with cubicles, where she had her desk, and the enclosed space with Wet Lab, 3D Print Room, and Testing Room. The only area to which PO2 had very limited access was the Clean Room. During the observation period, PO2 obtained access to the Clean Room twice and could enter the area only with someone who had special credentials. PO2 spent most of her time shadowing the AP Lab members as they worked in the Wet Lab, 3D Print Room and Testing Room, taking field notes on her experiences and any activities and interactions she observed. She noted the conversations between the lab members, and the interactions during the online lab meetings. PO2 took also notes of the informal chats she had periodically with each AP Lab member. During those chats, PO2 asked the AP Lab members to clarify, provide background for their research activities, share their previous educational experience, and talk about other topics that were of interest to the lab members. While observing the research activities of a given AP Lab member, PO2 inquired about the observed activity and what learning it required and asked the AP Lab members to think out loud while performing the activity. Wherever possible, PO2 documented daily research activities using audio and videography, and photography. In addition to the observation in the lab, PO2 conducted interviews with the AP Lab members.

Virtual participant-observation in the AP Lab

Even though the in-person research activities in the AP Lab had resumed by the time PO2 joined the Lab, they continued to have their weekly lab meetings online. During those meetings, the AP Lab members presented their work in progress, practiced their presentations (e. g. dissertation proposals), offered feedback and advice to each other, as well as checked on the main aspects of the Wet Lab, such as the safety, waste management, and inventory of the chemicals. PO2 participated in the online meetings, recorded them and took field notes on the interactions between the lab members.

Data analysis

In accord with Grounded Theory, data collection, analysis and theory building are not performed in a linear fashion but are intertwined, with one informing the other in an ongoing process until the saturation is reached, that is when nothing new is being added to the data. The work reported here is still in progress; therefore, the analyses presented here are limited to learning episodes documented in MHR Lab and interviews with a graduate student and a former mentor in AP Lab.

Data analysis started with examining the field notes of the observed events and grouping them into themes related to learning as it unfolds within labs, understood here as spaces where research activities take place. Nowadays, these spaces not only are salient physical spaces containing various equipment, but also virtual, online spaces. "Labs" also convey the meaning of research agenda, around which a group of people is organized [28]. Therefore, when annotating the learning episodes, we focused on the interactions between the PI and lab members (in mainly MHR Lab); the detailed data analysis and discussion of learning in MHR Lab are presented elsewhere [37].

The interviews with a graduate student in AP Lab (NM1) and with a former mentor (PDM) in AP Lab were audio-recorded and areas of interest pertaining to learning with others in the lab have been identified and transcribed. At the time of preparing this report, two coders, a white female cognitive scientist and a white male research assistant and philosophy graduate student, independently coded the areas of interest in the interview with NM1. They used a Grounded Theory approach [38] to identify meaning units and compare them to one another to uncover thematic trends in the interviews. Another coder, a white male philosopher, assisted with identifying themes among the coded meaning units about the interviewees' experiences with and understanding of learning, mentorship, and professional formation in a research laboratory. The coding activities of the interview with PDM are still ongoing, and we will only report preliminary findings on this interview.

In this report, we analyze the impact of leadership-mentorship on learning and professional formation. The themes that emerged through the analyses of the field notes and the interviews can be grouped as follows: (1) scaffolding or structured activities; (2) self-directed and self-regulated learning; (3) peer-to-peer learning, and (4) independence in research activities. In addition to that, we analyzed the "learning themes" in relationship to the degree of a leader-mentor presence in learning activities in MHR and AP labs.

Results

The results presentation is divided according to the themes we identified through the analysis of field notes and email correspondence from MHR and AP labs, and interviews with the MHR lab members. The detailed analyses of two themes, *Self-directed and self-regulated learning* and *Scaffolding as structured learning*, have been described in detail in [37]. In this report, we present a summary of these analyses corroborated with the results from two interviews with a graduate student and former postdoc mentor.

We applied Levitt's approach to Grounded Theory to code the meaning unites and arrive at higher-order categories [38]. Through the iterative coding process, we identified 37 meaning units in the interview with NM1. These units were then compared to one another and 14 initial categories were identified. The categories capture the following meanings of NM1's learning experiences: (1) Obstacles and limitations; (2) Motivations; (3) Misconceptions about Ph.D. program; (4) Foundations and Focus; (5) Success/Survival; (6) Program comments; (7) Peer-to-peer learning; (8) Self-directed learning; (9) Mentoring & skill-building; (10) Social mentoring; (11) Goals as a mentor; (12) Mentoring as coaching; (13) Independence; (14) Why-questions. A similar coding process yielded 28 meaning units in the interview with a former AP lab mentor, PDM1. The following initial categories reflect PDM's understanding of their role as a mentor: (1) Students' independence; (2) Students' peer-to-peer learning; (3) Teaching/mentoring through failure; (4) Social mentoring. It is important to note here that work on the student and mentor hierarchies of meanings is still ongoing. Table 12 provides a summary of the themes emerging from NM1 and PDM included in the subsequent presentation of results.

Table 2. Common themes on learning, teaching, and mentoring experiences in the interviews with AP Lab graduate student, NM1, and a former AP Lab postdoc mentor, PDM.

Interviewee: Graduate Student NM1	
Theme	**Theme Description**
Peer-to-peer learning	Other, more experienced/ knowledgeable members of the research team were an important resource for learning knowledge and skills.
Self-directed learning	Some learning was done on one's own, through individual effort.
Mentoring & skill-building	Working with a mentor for skill-building & developing expertise
Social mentoring	Mentors provide social support.
Independence	Learning/developing on one's own, without close mentorship.
Interviewee: Former Postdoc Mentor, PDM1	
Theme	**Theme Description**
Students' independence	Students work on their own projects to understand the scientific process.
Teaching/mentoring through failure	Emphasis on showing what went wrong in the experiments to improve and learn.
Students' peer-to-peer learning	Less experienced students learn from more experienced students; they talk about their projects all the time.
Social mentoring	Being open to students and for the students so they can ask questions; making sure they meet and interact in a relaxed atmosphere.

Self-directed and self-regulated learning

Based on our observations, learning in the engineering research labs operated as self-regulated learning. Self-regulated learning indicates that the learners take control of their learning to conceptualize, design, and execute [39]. Self-regulation is essential to advance in any academic field, and cultivating self-regulated learners is one of the central goals in higher education [40]. Each member of our field site lab had their research project to conduct. They might seek guidance or help from their advising faculty or more experienced peers to choose the topic, to plan the research procedure, and to solve the problems they encountered, but the decisions were their own to make. According to the emerging cultural model of MHR and AP lab members' self-regulated learning (described in detail in [37]), students chose what they wanted to learn and made plans about how to proceed. They controlled the procedure and revised or altered it as they saw fit. These self-regulated learning processes were closely related to the research projects they conducted and were still clearly observable when the unexpected COVID-19 pandemic crisis occurred. To adjust, the lab members found 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 they participated in a project to fight against the pandemic using their expertise.

The importance of self-directed learning and learning on one's own emerged also as one of the themes in the interview with NM1, a graduate student at AP Lab (see Tab. 1). Throughout the interview, NM1 emphasized that to "survive" the Ph.D. program one has to be perseverant and motivated, and one has to learn on one's own: "So outside of the classroom is where I've gotten most of these skills and quote-unquote expertise in 3D printing." NM1 also pointed out that mastering the skills, and learning about research fundamentals and research methodology in chemistry happened mostly through engagement in the projects:

> "(…) it was really just using those skill sets, learning how to use the different equipment such as the UTM, DMA, DSC, TGA, through-through that experience. And then reading papers, learning how to do the synthesis on that project. So that's where I did develop a lot of the hands-on skills, or yeah, hands-on skills."

NM1's understanding of self-directed learning, as a process initiated by students who then decide what and how to learn a skill or knowledge related to their research projects corroborates our earlier observations in MHR and AP labs.

Scaffolding as structured learning

Self-regulated learners actively seek feedback from external sources such as teachers' comments and peers' contributions in collaborative groups and this external feedback helps make self-regulated learning effective [41]. During the observation of the MHR Lab, we noticed that the feedback from the PI to the graduate students in the lab worked like a scaffolding strategy. The PI differentiated their feedback according to the current level of skills and abilities of the student presenting at the lab meeting. Providing different feedback based on the learner's ability and situation to help the learner complete the task reminded us of the pedagogical strategy known as "scaffolding." In general, scaffolding is a strategy in which an expert provides the necessary support for a learner to accomplish a specific task, differentiated according to the learner's ability and situation. As the learner obtains more independence, the expert's support is gradually diminished. Typically, scaffolding is part of teaching strategy implemented at different levels of instruction (a task, a syllabus, a curriculum). But what we observed in MHR Lab occurred spontaneously and without formal planning or instructional design. We call this type of instructional strategy an "organically occurring scaffolding" and discuss it in more details in a separate publication [37].

Peer-to-peer learning

Peer-to-peer learning, understood as partnering with more experienced lab members when learning skills and fundamentals of research, appeared in the interviews with the graduate student, NM1 and with PDM, a former postdoc mentor at AP lab. More knowledgeable and experienced lab members were to NM1 an important resource for learning about research in chemistry and material sciences. "A lot of it has been (…) talking with other people that had expertise. So like (…) two postdocs that I've talked to a lot about polymers in general" and "Yeah, so a lot of it so, a lot of it was due to one project, which was the photo patternable shape memory polymer project that I've been on. And that was with (…) a former postdoc in our lab, a former student in our lab."

PDM's observations of the students in the AP lab point to the common practice of students who work in the same area to "discuss their work amongst each other all the time." PDM shares also that the students are often in an *apprentice* relationship with one another, where the less experienced student learns research skills through assisting the more experienced lab members in their research, and gradually gains independence in their own research.

> "So, one of the students is [NND2], so he's one of the younger students. And he is amazing with CAD designs, but he kind of works kind of apprenticeship with [NND1] and [former graduate student], and kind of saw where he could fit in to make some of their devices better, help them fabricate, he would help them in their projects. And now he's kind of off-shot his own projects off of those. And so now he's kind of taking lead on the next generation of devices that are, they've gone from, say, a passive device, which is just stimulation, but now they're going to an active device where they have these more complex circuits that [NND2] is designing."

For graduate students with less experience, collaborating on a research project with more advanced lab members can be at times a source of confusion and frustration, especially when more experienced colleagues fail to explain the context of their research projects. NM1 reminisces:

> "And I would, I remember getting so frustrated at the other like members that were working on this together because I always wanted to know, like, why are we doing this? What's the bigger goal? Is it to help with just making the fabrication easier? Is it just like, is it to make this new functional thin, thin film? Like what are we trying to do? And there was always like this back and forth of like, 'It can be used for this, it can be used for this.' We don't just want to box ourselves into saying that it can be used for this one function. And I never quite understood what they were trying to say 'cause there were conflicting messages that I was hearing."

Independence in research activities

Becoming an independent researcher, who can go through the scientific inquiry process on their own, is an important part of professional formation according to AP Lab members. As explained in the section on the field description, in the AP lab, the graduate students' research projects focus on various materials, like polymers, or on implantable microelectronic devices. The PDM, the former postdoc, and mentor explains that the students work on their individual projects, and at the same time they collaborate on similar projects with other lab members. In this way they "(…) they're kind of running in parallel, and they bounce of off each other". However, the emphasis seems to be on the students' individual work: "But we do want them to have their own project and to have conceptual ideas of what, how to go from the beginning to designing experiments and actually discussing those conclusions," emphasizes PDM.

The theme of independence emerges also in the interview with NM1. In their experiences, becoming an independent researcher is a function of learning on one's own and with more experienced peers and understanding the scope of research and fundamental concepts. This is how NM1 tries to instill independence, in form of the ability to formulate questions and design experiments, in his undergraduate research assistant (URA).

> "I want him to start developing those, that skill set of, okay, this is "why this is happening"; "Why do you think this is happening?" "Like can you explain it back to me?" Because those are the skill sets that I've found translate the most not only between sections of science, but in any industry if you can learn how to ask questions and break down the question of "Why?" Then you can answer a bunch of different questions across different fields."

And:

> "And then yeah, so really that's been my main focus with him, is trying to teach that skill set, and now that we're done with the main, with this part, I have him essentially trying to come up with a few questions that he wants to answer. And then we can go over the test that we can run and then where we go from there."

The similarity of PDM and NM1's views on becoming an independent researcher can be traced back to the times when PDM was a postdoc and mentor at AP Lab. NM1 worked on polymers and often sought advice and guidance from PDM, whose background was also in chemistry and polymers (this theme will be also explored in the next section).

Learning, professional formation, and presence of a leader-mentor

Perceptions of and expectations for PIs

The way the MHR and AP lab members understand their learning and professional formation is informed, on the one hand, by their expectations of the role a leader-mentor (a PI, postdoc mentor, lab manager, and so on) plays in their becoming of independent researchers, and on the other hand, on their experiences with a leader-mentor present in the daily activities in the labs.

When comparing the field notes on the two labs, the PI at the MHR lab directly engaged their students by organizing and leading the lab activities and meetings, by structuring learning through scaffolding, and by active involvement in the "benchtop" activities. One episode showcasing the PI's involvement in benchtop activities with one of their Ph.D. students, GS., has to do with problem-solving around a malfunctioning robotic needle (the case is described in detail in [37]). GS developed an algorithm that uses three-dimensional force detection to predict the dense structure in front of the surgical needle faster than human responses so that it can prevent needle buckling during the surgery. During one of many testing procedures, GS noticed that the robotic needle was not working properly, and they said that they could not figure out what caused the problem or what part of the system had a problem. They enlisted help from the PI and together they tackled the problem. During this problem-solving process, the PI did not just verbally direct or teach GS. Instead, the PI acted as a colleague sharing ideas and thoughts with GS while they were working on the task. Such direct methods of PI's engagement are partially the result of the MHR Lab size and the uniformity of the research agenda. At the time of participant-observation, five graduate students and one, recently hired postdoc worked at the MHR lab on automated surgical equipment.

Direct involvement of PIs in the "benchtop" activities is an exception, not a rule. In larger laboratories, with diverse research agendas, the tasks of leading, overseeing, and mentoring graduate students are often distributed among the postdoctoral researchers [28], [29]. In the AP lab, a much larger lab (at least at the onset of our participant-observation) the role of the organizer of lab activities, including the meetings, was assumed by a postdoctoral researcher. What our interviews and observations at AP Lab revealed, however, is the misalignment of graduate students' perceptions of and expectations for a leader-mentor role, and the actual roles the PI and the postdoctoral mentors played in the graduate students' learning and professional formation.

Elsewhere [28], [29] it has been demonstrated that when supervising a research lab, the PIs typically assume responsibilities for aiming at maintaining the integrity of the lab for its members and the world outside. That is for formulating and representing the research agenda of their labs, disseminating knowledge accumulated through research, securing funding, maintaining contacts with other labs and institutions, attracting students to the lab, advising, and finally, supervising, and oversight of their labs' research activities. The data gathered through our participant-observations suggest that the AP Lab PI did assume such responsibilities. On many occasions, the students mentioned that the PI meets at least once a semester with each graduate student to check on their progress. During the meeting, the students present the summary of the milestones reached and they discuss the next steps. The PI also makes sure that the students are well prepared for their dissertation defense and are aware of various career options, and to that end, he meets with them more often the closer they get to the actual defense. This is how NM1 talks about it:

> "(…) within the past like four, I guess three months, I've seen him probably the same amount of times that I've seen him the past like four-and-a-half years, and have talked to him like on the phone, and he's been available. So yes, he's been helpful for this last step on getting everything ready. And he's given me his vote of confidence that he's not worried that I'm going to have any problems with the defense or the thesis, so it's nice on that end."

And

> "PI has been helpful in that side of it. So at the, more towards the end of the career, my time here, he has been more willing to talk about career opportunities, people that he knows, different professors he has that he relationships with that may know someone in that field. So he has helped out with that side."

There is a tension between the PI's role as it has been fulfilled by them, and the NM1's expectations of what the role of a PI, a leader, and mentor should be. In the first quote, the student mentions that while the frequency of meetings with the PI increased during the 3-4 months before the dissertation defense, the meetings during the previous years were infrequent in the student's view.

The sense that the PI is somehow absent from the AP Lab students' activities, or rather—an expectation of his engagement—could also be seen in another graduate student's account. NM3, whose background is in engineering, works on biodegradable polymers and at times needs guidance in the process of polymer formulation. NM3 was trying for some time to formulate a sample of the polymer to start the testing procedures but was not successful in recreating the formula based on the accounts in the literature. However, NM3 recently discovered that students in another material sciences laboratory work on similar polymers and that they can help NM3 with the formulation of the biodegradable polymer sample. While eager to share the news with the participant-observer, NM3 pointed out that “If I knew them earlier, I wouldn’t be two years behind.” “[PI] was not here to make introductions.”

A mismatch of expectations towards the role of the PIs with how the PIs fulfill their role can lead to feelings of being left to one’s own devices, of missing out on a close working relationship with one’s advisor, and to frustration with the learning process through trial and error. However, the perceived absence of a PI can also create opportunities for the lab members to embrace their agency in the learning process and to become skillful and independent researchers, as showcased in NM1 and PDM1’s accounts on peer-to-peer learning and independence in research presented in the sections above.

Perceptions of and expectations for postdoctoral mentors

As mentioned earlier, the mentoring tasks are often distributed among the senior staff in research labs, like senior researchers and postdoctoral students, and AP Lab was not different from other documented laboratories in that regard. PDM, a postdoctoral student in chemistry and polymers, saw his role as being responsible for guiding graduate students’ learning and professional formation. In particular, he embraced guiding or mentoring through failure:

> “I’ve been a proponent of ‘You learn through failure’. We don’t learn from successes; we don’t question a success. But when we have a failure, we always question ‘Why did it fail?’”

Much like MHR Lab’s PI, PDM saw a failure as an opportunity to lead the junior AP lab members through the process of scientific inquiry, guiding them through a discovery that science is not a linear progression towards success, but rather an iterative process:

> “And so, (…) the graduate students will have a failure and they'll look at the literature, they'll talk to me, they'll talk to a, another professor and say, ‘Hey, I tried this. This didn't work. It's not what I expected. Why is that?’ And we kind of lead them through." (…) And so, I'll go with them, and like, ‘Hey, well, this is kind of what happened here.’ And I'll write on the board. And we'll sit there and talk (…)."

Besides *mentoring through failure*, another prominent theme in the interview with PDM is the idea of *being present for the students* (“my office is always open for the students to just walk by when they have questions and I’m willing to sit with the student for any amount of time to help them out.") and creating *atmosphere conducive for to share mistakes and failures* (“We wanted relaxed atmosphere for the students. They work better in it than in a kind of atmosphere that’s very strict and rigid, where students are too scared to do anything or to fail."). Pre-COVID pandemic, the PI, PDM initiated lunches for students to share their research and to socialize, especially with those who worked on different research projects. “It is important for the students to have the lab meetings, not just to discuss the projects, but to talk to other people.", PDM shared in the interview. The lab meetings continued virtually during the COVID pandemic, and once the most severe restrictions have been lifted, PDM tried to be back in the lab to assist the students with their research.

> “I still tried to remain on campus most of the week. The students know when I’m on campus and they can come to my office. My office is still open. Wearing a mask, but they can come in (…) This current week I had students coming each day to discuss and I didn’t get my work done because of the constant flow of students coming in.”

Unlike the apparent mismatch between the AP Lab students' perceptions of the PI's role in one's learning and professional formation and their actual responsibilities, there is an alignment of the expectations for the postdoc mentor and their role in and engagement with the students' learning. According to NM1, PDM was particularly helpful with critical appraisal of the students' research projects and guiding them with questions. As NM1 evokes:

> "It was more just guidance (…) it's more (…) like hey, like 'have you looked into this', or like 'why do you think this is happening', like 'do you have an answer', 'do you have a theory on how or why this is working the way it is?' So it's more been in that mentorship role than the hardcore science of like, you should look into do this experiment, and then this experiment and this experiment."

PDM was also instrumental in providing social support for the AP Lab members. In NM1 words:

> "(…) taking the time to meet one-on-one, have a like personal and like scientific conversation of like how things are going, being a critique, or a critic for the research. And he's like, well, if you can handle my questions, then the defense is going to be easy. So really coming from a place of caring and versus just leaving us out to dry."

Before the PO2 assumed her role as a participant-observer at AP Lab, PDM left for another position. They are, however, still present at the virtual lab meetings and to offer their support and guidance. NM1 reminisced: "Really comes to mind for me just because of I, he like, we've talked about how busy he is at work and um how they're ramping up with their R & D division being bought (…) And even though there's all that craziness going on, he's still taking the time to meet [us]."

Discussion and conclusions

Two research questions guided our analyses of learning experiences in the MHR and AP Labs: 1) What is the role of peer-to-peer learning in research laboratories, and how do lab members learn from one another? 2) What role do mentors play in the learning processes in the lab, and how does this role change depending on the leadership style and level of the mentor?

With respect to the first question, the themes we identified through the analyses of fieldnotes and interviews point to *self-directed learning*, where the lab members in MHR and AP labs decide on what they need to learn and solicit help from other, more experienced and knowledgeable lab members. Self-directed learning is not only the way that members of the laboratories gain knowledge and skills related to their specific research projects; it is also a metacognitive skill that is learned through participation in the research. As illustrated in the case of NM1, through students' work and engagement in scientific inquiry, they become independent researchers and workers. The case of PI from the MHR lab demonstrates also that self-directed learning is taught by senior laboratory members or directors through an organic, unintentional *scaffolding strategy.*

We also presented cases of *peer-to-peer* learning (interview with NM1) when more experienced lab members guide their less experienced peers through the laboratory and research activities. As we demonstrated, it is not always a smooth process (NM1's confusion about research scope), perhaps because they have not developed the skills of scaffolding activities for junior members that lab directors or postdocs have. Much of the pedagogy of practical laboratory learning seems unplanned and unguided, at least in the field sites we looked at. A better understanding how these learning processes unfold, self-reflection on the laboratory as a site of teaching and learning by all lab members, and conscious adoption and deployment of pedagogical strategies in the design of laboratory activities may improve first-order and metacognitive learning. Students should learn to approach their work in the laboratory as not only an activity where they are *learner* and *research worker* but also *teacher.*

Regarding the question about the role mentors and lab leaders play in students' learning, what we documented suggests that laboratory directors can learn from best practices of scaffolding as demonstrated in the case of PI from MHR Lab in both their interactions with their lab members and their design of lab activities and interactions. What we also find in the presented cases is that it is not as much presence or absence of a leader-mentor in the laboratory that may be problematic, but rather the lack of understanding that the roles of postdocs and senior students should be understood as partially pedagogical and that the postdocs and senior students should receive more explicit guidance on pedagogy and mentoring their younger colleagues.

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Response to the Reviewers

Dear Reviewers and ELOS Session Chair,

Thank you for your encouraging comments and detailed reviews, which we found very helpful in revising the paper. Please find out responses below, organized according to page-by-page suggestions provided by Reviewer 1. We believe that our responses to Reviewer 1 will satisfy suggestions and comments left by the other two reviewers. Our responses are marked in green.

#1: Page 1, Title: I would like to suggest that you change “lab” in your title to “research lab”. The reason is that most of the ELOS division is about supporting teaching labs in undergraduate mechanical engineering, so the term “lab” might be interpreted by the reader to mean a teaching lab environment. If you state clearly that this is a paper involving a research lab, there will be less confusion at the start.

The title has been revised.

#2: Page 1, Abstract: I would recommend starting the draft of your work with both the title and abstract on the first page. I know that the abstract is contained on-line, and that is where I read it; however, it would be great to have it in the paper too.

Per the reviewer’s suggestion, we have included the abstract in the manuscript. Please know that we followed the manuscript preparation guidelines, which said it was not necessary to include the abstract in the manuscript.

#3: Page 2, First Sentence: “The study reported here is part of four-year research…” – please add an ‘a’ between ‘of’ and ‘four’.

Revised.

#4: Page 2, “Authentic research experiences” section, First Paragraph: When citing multiple sources, please use the format [1, 2] or [10 - 14]. Fix all instances throughout the paper please.

We checked the IEEE formatting that suggests using [10-14] formatting for multiple citations and we decided to use it throughout the paper.

#5: Page 3, “Learning in the laboratory” section, First Paragraph: Fix spacing between words and references. There are two instances in the first two sentences where no space is provided. Check remaining instances of reference citations for similar issues.

Revised.

#6: Page 3, “Learning in the laboratory” section, Second Paragraph: Fix the typo of “distribthe uted” to “distributed”.

Revised.

#7: Page 4, “Leadership and mentorship” section, First Paragraph: It looks like there is a double period after the [23] reference?

Revised.

#8: Page 4, “Leadership and mentorship” section: The style of your writing switches to a mode in which you don’t refer to the authors names but instead refer to reference number, e.g., “As [23] explains…” versus the “Nersessian and Newsletter…” in the previous section. I would suggest sticking to one style and staying with it rather than having this awkward switch.

All of the citations in the “Leadership and mentorship” section are now at the end of the citation.

#9: Page 5, “Research questions” section: In your list at the end of the paragraph you use a 1) style then a 2. style for your enumerated list. Stick to one style/format please.

Revised.

#9: Page 5, “Cognitive ethnography” section: Is ‘painstaking qualitative analysis’ a technical term in the field of cognitive ethnography? If so, keep it. If not, the term word ‘painstaking’ should be removed. I feel that it is employed here to provide some kind of emotional response to how some might react to ‘qualitative’ (i.e., someone who spends their time doing quantitative research might think qualitative research is suspect, but if it is ‘painstakingly’ accomplished then maybe they might trust it more.). Both qualitative and quantitative data can be ‘painstaking’ to collect an analyze. I guess we should hope that all data is carefully collected, analyzed, and scrutinized.

Revised per Reviewer’s suggestion.

#10: Page 6, “Field sites” section: Perhaps use a different style to denote the sub-sub section headings for the two laboratories. As it stands, these hardly stand out as section headings.

Again, we have followed the manuscript guidelines that suggested the headlines for sections and subsections we ended up using. But we agree that it could be hard to parse subsections headlines from the text. To address this issue, we added underline to the subsections.

#11: Page 7, “Advanced Polymers Research Lab” subsection: At the start of this section, can you provide the overall timeframe (start month/year and end month/year)? This would be consistent with the first research lab where we knew almost immediately the timeframe of the study.

Clear timelines for participant-observation in both labs is now added.

#12: Page 8, “Advanced Polymers Research Lab” subsection: Trying to read/follow all of the various students and their alphanumeric designations is confusing. Can all of this be provided in a table in the body of the paper (or an Appendix) for reference? It would allow the reader to better differentiate the codes and how they relate to the labs, level of researcher, etc.

Per the Reviewer’s suggestion, the table is now added to clarify the code names of AP Lab members.

#13: Page 8, “Advanced Polymers Research Lab” subsection: Add ‘the’ before “Clean Room” (located in the second full paragraph on the page).

Revised.

#14: Page 9, “Positionality of the participant observers” subsubsection: Add a comma within the parenthetical statement in the first sentence to separate observer designations at the two labs.

Revised.

#15: Page 9, “Positionality of the participant observers” subsubsection: NOTE THE IMPORTANCE OF THIS COMMENT AND PLEASE ADDRESS. Perhaps this is due to my lack of knowledge of the ethnography process, but this paragraph describes how the participant observers interact with the individuals they are studying. I don’t understand this at all. Shouldn’t the observers be just that…observers? If they now participate in the study – and as described it sounds like they can have an influence on the outlook/work of the students they are researching, then what does this say about any of the results that will be presented? I don’t think that I would be the only person in the ELOS division to have a lack of knowledge of this type of study; however, it seems that there needs to be a full explanation of whether subject-observer interactions are typical of a work like this or if this is something out of the ordinary.

We have added a ½ paragraph on p. 5 and a footnote on p. 9 that addresses this comment.

#16: Page 9, “Participant observation in the MHR Lab” subsubsection: It looks like there is an extra space between ‘desk’ and ‘at’ in the second sentence.

Revised.

#17: Page 10, “Participant observation in the AP Lab” subsubsection: It looks like there is a need for a space in ‘toprovide’. This is located a bit past half-way through the paragraph.

Revised.

#18: Page 10, “Data analysis” section: Remove the comma in the first sentence as it appears unnecessary.

Revised.

#19: Page 10-11, “Data analysis” section: There is a parenthesis that is on the very end of page 10 (“(mainly”) that does not seem to end anywhere at the top of page 11. Please fix.

Revised.

#20: Page 11, "Data analysis" section, Second Paragraph: The authors identify the ethnicity of the scientists and assistants but not their gender or citizenship status. But previously when describing the positionality of the participant observers, the gender and citizenship status was provided but not the ethnicity. Can the authors go back and be consistent in their reporting, if appropriate, of all of the information that is reported about those involved in the study. Perhaps this is not relevant, so I apologize if the inconsistency is something specific to the authors area of expertise or if that is typical of a ethnography style paper.

The best practices for qualitative research emphasize disclosing any information of the researchers (participant-observers and coders) that create important context for interpreting the results. That's why we have chosen to disclose the gender, age, and immigration status of the participant-observers and gender and ethnicity of the coders. As far the study participants, including demographics is relevant only when this information enters the analysis of results.

#21: Page 11, "Results" section, Second Paragraph: The term 'grounded theory' is not capitalized here, but was capitalized when first introduced toward the top of the page. Please choose a consistent style.

Revised.

#22: Page 12, "Self-directed and self-regulated learning" subsection: Please check typos (missing periods and extra "(") in the first and second sentences.

Revised.

#23: Page 13, "Scaffolding as structured learning" subsection: In the third sentence you disclosed the gender of the PI in the MHR lab. Not sure if you were supposed to do this as earlier you mentioned that the gender of participants in the study would not be disclosed. And, similarly, the name "Dr. Mac" the PI of the MHR Lab is disclosed in the longer quote from the email. This should be removed. There are other instances in which the gender of the PI is disclosed.

We have removed the study participants gender identity from the results description.

#24: Page 15, "Learning, professional formation…" subsubsection, Second Paragraph: I am not sure if giving the name "Kara" to the PhD student protects their identify. As you mentioned, the labs are small, and "Kara" could imply a female gender. Is there a way to create a gender-neutral identity that the reader can follow and also maintain anonymity of the individual?

The code names for the members of MHR lab have been change to remove any link to gender identity.

#25: Page 15, "Learning, professional formation…" subsubsection, Second Paragraph: Please add a space to break up '5graduate' in the last sentence of that paragraph.

Revised.

#26: Page 17, “Learning, professional formation…” subsubsection, Second Paragraph: The phrasing “…can for sure…” in the first sentence sounds too casual. Please re-write to be more formal and consistent with the formality of the paper (aside from the direct quotes from students).

Revised.

#27: Page 19, “Discussion and conclusions” section: It seems like the conclusions of this paper are geared toward PIs and Post Docs and what they should change to meet the needs in students learning. However, one could argue that research labs are an environment in which the students (graduate, undergraduate) should come in with a better understanding of what will occur and what is required of them rather than what will be provided by supervisors. Perhaps I am not understanding the audience of this study, but going back to the start the authors had mentioned that learning in research labs is being more regularly pushed as an opportunity for undergraduates. If this is the case, then the authors should reinforce this idea in the conclusions by suggesting that improvements in learning for undergraduates involved in these research labs could be improved with more training of PIs and Post Docs. This would benefit students who have signed up for REU experiences.

Based on our preliminary results, we don’t see how we have anything to say about students needing to come in with a certain preparation. It is possible that such instruction could be designed prior to lab work, but we don’t know what that would look like. However, we have made a few small edits to take the perceived pressure off PIs and Postdocs – a lot of this is about lab design and self-reflection for everyone. Hopefully it addresses the issue.

#28: Page 21, References Section: Check for typo in reference [35]. There appears to be a “.)” which I do not understand.

Revised.