

3-2017

Learning Competencies Through Engineering Research Group Experiences

Brian A. Burt

Iowa State University, burt@iastate.edu

Follow this and additional works at: http://lib.dr.iastate.edu/edu_pubs

 Part of the [Bilingual, Multilingual, and Multicultural Education Commons](#), [Educational Assessment, Evaluation, and Research Commons](#), [Higher Education Commons](#), and the [Science and Mathematics Education Commons](#)

Recommended Citation

Burt, Brian A., "Learning Competencies Through Engineering Research Group Experiences" (2017). *Education Publications*. 51.
http://lib.dr.iastate.edu/edu_pubs/51

This Article is brought to you for free and open access by the School of Education at Iowa State University Digital Repository. It has been accepted for inclusion in Education Publications by an authorized administrator of Iowa State University Digital Repository. For more information, please contact digirep@iastate.edu.

Learning Competencies Through Engineering Research Group Experiences

ABSTRACT

Purpose - In some fields, research group experiences gained in laboratories are more influential than the classroom in shaping graduate students' research abilities, understandings of post-graduate careers, and professional identities. However, we know little about what and how students learn from their research group experiences. This article explores the learning experiences of engineering graduate students in one chemical engineering research group to determine what students learned and identify the practices and activities that facilitated their learning.

Design/methodology/approach – Ethnography was utilized to observe the experiences of one 20-member research group in chemical engineering. Fieldwork included 13 months of observations, 31 formal interviews (16 first-round and 15 second-round interviews) and informal interviews. Fieldnotes and transcriptions were analyzed using grounded theory techniques.

Findings – Research group members developed four dominant competencies: (1) presenting research, (2) receiving and responding to feedback, (3) solving problems, and (4) troubleshooting problems. Students' learning was facilitated by the practices and activities of the research group (e.g., weekly full group and subgroup meetings), and mediated through the interactions of others (i.e., peers, faculty supervisor, and lab manager).

Originality/value – This study adds to the engineering education literature and contributes to the larger discourse on identifying promising practices and activities that improve student learning in graduate education.

Keywords: learning, graduate education, engineering, research group experiences, sociocultural, ethnography, grounded theory

Learning Competencies Through Engineering Research Group Experiences

What is learned during graduate education in engineering, and how (and where) does this learning take place? Although there is a growing volume of scholarship regarding graduate education, there is no domain-specific corpus focused on engineering. Without sufficient discipline-specific scholarship on graduate student learning, there is an assumption it is the same in all fields.

This article adds to the engineering education literature on graduate student learning in science, technology, engineering, and mathematics (STEM) research groups. In science and engineering fields, the research group serves as a critical social context where students' learning and identities (scholarly and professional) merge (Burt, 2014). Thus, this article addresses the following research questions: What competencies do doctoral students in engineering learn through participating in research group experiences? And how do they learn these competencies?

A sociocultural perspective on learning is used to provide insights into how a research group serves as a community of practice where education takes place. This theoretical framework guides investigations around concepts of contexts, mediation and interactions, participation, and identity development. Utilizing its concepts and ideas, this article investigates the learning experiences of graduate students in one chemical engineering research group. Four dominant competencies are found to have been developed: 1) presenting research; 2) receiving and responding to feedback; 3) solving problems; and, 4) troubleshooting problems. Key practices of the research group included attending weekly group and subgroup meetings and interacting with others in the group. As the findings from this study will demonstrate, these practices facilitated graduate

students' learning of the four dominant competencies. This in turn improved their ability to participate in the research group, department, and institution.

GRADUATE EDUCATION, TEAM-BASED SCIENCE FIELDS, AND LEARNING

Existing research on graduate education tends to conceptualize learning as primarily occurring within departments, between students and their faculty advisors, or between students and their peers. Within some departments and disciplines, there appear to be signature practices that influence students' learning. In a study of doctoral students in two fields – neuroscience and English – Golde (2007) identified two pedagogical practices that shaped students' mastery of literature: participating in a journal club in the neuroscience department, and creating a list (or canon) of seminal literature within their field in the English department. Key to these practices was that the two departments identified their respective practices as important for student learning, and organized and coordinated these efforts. Additionally, both practices included some form of interaction with others (e.g., being placed in small groups within the journal club and/or discussing work within a large group), and co-construction and sharing of knowledge across participants (e.g., an iterative reading list being generated over time, and shared with newer cohorts of students).

Departmental practices are not the only facilitators of students' learning. Much of the research on graduate education also shows that specific aspects of learning occur through students' interactions with their advisors (Antony and Taylor, 2001; Austin, 2002 and 2009) and with their peers (Baker Sweitzer, 2009; Baker and Pifer, 2011; Gardner, 2008; Lindholm, 2004). For example, in fields where team-based research experiences are integral, like science and engineering, students also learn through participation in

research groups. Students engage in collaborative research practices with peers and the faculty supervisor in the lab. In a study of six graduate students in chemistry, Bhattacharyya and Bodner (2014) note that students' participation in research resulted in a deeper level of understanding of problem-solving techniques and concepts previously discussed in coursework, as demonstrated by their ability to engage in deeper chemistry-related scientific conversations and research practices. Similarly, in a study of graduate students and alumni, Villa *et al.* (2013) describe how some students improved their writing skills through collaborative writing with a faculty supervisor. The authors describe how participating in research activities and practices transformed students' self-perceptions; students' confidence in their research ability increased as a result of their social interactions and learning within the research group. Taken together, their findings highlight students' learning of research through the social interactions – and participation in the practices and activities – of research group experiences. Further, these studies highlight the unique nature of research group experiences as key sites for social learning.

The corpus of scholarship on graduate students' learning and research group experiences includes domain-specific samples from a wide array of fields (Austin, 2009; Antony and Taylor, 2001; Baker Sweitzer, 2009; Baker and Pifer, 2011; Holley, 2009; Sallee, 2011; Vekkaila *et al.*, 2012). Including a domain-specific focus provides more precision around the kinds of learning that take place within a bounded context. Other studies include mixed samples with participants from multiple disciplines (Baker, Pifer, and Flemion, 2015; Gardner, 2007 and 2008; Golde, 2005 and 2007). These help increase the broad knowledge base on student learning, while simultaneously distinguishing practices and activities within and across fields of study.

Despite the growing body of work on graduate students' learning and research group experiences, there are some notable gaps. First, knowledge regarding the practices and activities that facilitate graduate student learning in engineering is limited. Without such knowledge, it is unclear whether findings and recommendations based on students in other fields also apply to those in engineering. Thus, research on engineering students would both add to the engineering education literature, and help identify promising practices and activities that could improve student learning in graduate education in engineering and other fields.

Second, socialization theory is often advanced to explain how students transition into graduate school and learn to complete various academic and professional tasks in their field of study and become scholars. It is also used to explain how they plan for post-graduate careers (Felder, Stevenson, and Gasman, 2014; Gardner, 2007; Gildersleeve, Croom, and Vasquez, 2011; Tierney, 1997; Weidman and Stein, 2003; Weidman *et al.*, 2001). In other words, socialization as a theoretical construct is often used to explain individuals' *adoption* of the norms, values, and traditions of their given community (Baker and Lattuca, 2010). What is not always apparent from these studies, however, is what students are *learning* and how this *learning* occurs. There are some notable exceptions that extend the traditional conceptualizations of socialization theory and begin to consider learning and competency development (see for example: Gardner, 2009; Holley, 2011). Yet, to better fill this gap, a sociocultural perspective is needed. "Sociocultural perspectives on learning" is an umbrella term encompassing a set of conceptualizations of learning: "situated cognition" (Brown *et al.*, 1989), "guided

participation/apprenticeship” (Rogoff, 1990), “situated learning” (Lave and Wenger, 1991) and “cognitive apprenticeship” (Collins *et al.*, 1991).

Sociocultural perspectives on learning emphasize how social interactions, in particular contexts and cultural practices, influence learning and development (Holley, 2009; Vekkaila *et al.*, 2012). In other words, the process of learning (i.e. knowledge and skill development) occurs through participating in the social activities of a particular community of practice. This theoretical framework is influenced by three key concepts: 1) context (the surrounding structures and the relationships within communities of practice); 2) mediation (interactions with members of the community and with the cultural tools – for example, its language, books, or equipment – that make it possible to engage in the community’s practices); and, 3) participation (engagement in the activities associated with the community of practice) (Wenger, 2010; Wertsch *et al.*, 1995; Wortham, 2004). As individuals participate in the practices of their community, they learn how to be members of that community. Thus, the unique context of the research lab, and the interactions within the lab, may equally contribute to what students learn, how they learn it, and their identity development. This study incorporates both interviews and observations to gain a detailed interpretation of students’ research group experiences and their influences on students’ learning and development.

METHODS

To address two research questions - *What competencies do doctoral students in engineering learn through participating in research group experiences? And how do they learn these competencies?* – this study used an ethnographic approach. Ethnography involves identifying and understanding cultural phenomena (Emerson *et al.*, 1995;

Fetterman, 2010; Spradley, 1979; Van Maanen, 1988; Wolcott, 1994) using multiple sources of data (what people say, observations of how people act, and artifacts that people use), over extended periods of time to generate hypotheses about particular cultures (Spradley, 1979).

Here, the ethnographic approach allowed the researcher to observe the interactions and activities (e.g., group meetings, conferences, social gatherings, dissertation defenses) of a research group in chemical engineering at Model University (pseudonym). This group will be referred to hereafter as the “Houston Research Group.” Table 1 includes the leadership team and full-time members of the group. (Part-time undergraduate student members and visiting scholars are excluded.) Further, because data was collected for a full year (September 2012 – October 2013), all student group members’ statuses were elevated by the end of the study. In the findings below, students’ status reflects their status at the time at which the data was collected.

Table 1: Profile of Study Participants

Pseudonym	Gender	Status*
Leadership Team		
Professor Houston	Male	Research Supervisor
Professor Lee	Male	Professor Emeritus/part-time
Dr. Randall	Male	Lab Manager
Core Group Members		
Lloyd	Male	Post-doctoral researcher
Emma	Female	Post-doctoral researcher
Brielle	Female	Ph.D. graduate, researcher
Gloria	Female	Fourth year Ph.D. student
Tiffany	Female	Fourth year Ph.D. student
Danny	Male	Fourth year Ph.D. student
Allen	Male	Third year Ph.D. student
Erik	Male	Third year Ph.D. student
Sherman	Male	Second year Ph.D. student
Vince	Male	Second year Ph.D. student
Ralph	Male	Second year Ph.D. student
Louise	Female	Second year Master’s student
Kelcy	Male	Engineer

* “Status” refers to a lab group member’s academic status at the end of data collection

Fieldwork included 13 months of observations, 31 formal interviews (16 first-round and 15 second-round interviews) and informal interviews (i.e., conversations held in passing that allowed the researcher to check interpretations). Through this extensive fieldwork, the researcher developed rapport with group members and gained their trust, which afforded him the opportunity to engage in formal interviews to ask specific questions about what was happening in the setting, participants' interpretations of activities and interactions, and how their research skills were developing.

All observations and informal interviews were documented through field notes. All formal interviews were audio recorded and transcribed verbatim. Grounded theory techniques (Corbin and Strauss, 2008; Merriam, 2009) were used to analyze data. Analysis began with open coding, determining initial categories per transcript that captured important information about a phenomenon. Next, the constant comparative technique was used to search for data across transcripts. The researcher then created categories, through axial coding, by looking for relationships across codes. Identification and refinement of codes and categories were iterated until categories were saturated and no new categories could be created. Finally, themes resulted from grouping of categories, and helped to generate theoretical propositions (i.e., hypotheses) for future testing.

FINDINGS

Establishing Contexts

Departmental and institutional contexts influenced students' exposure to and engagement with research. Engineering doctoral students admitted to chemical engineering at Model University are required to take courses, join a research group, and publish article(s) before graduating. These established requirements form part of the

departmental and institutional contexts that influence the research group's emphasis on research, presentations, and publications.

To meet the institutional goals of research productivity, Professor Houston (pseudonym), director of the Houston Research Group, implemented several research practices, the most dominant being weekly group and subgroup meetings, and lab work. The purpose of these practices was to teach students about – and assess their abilities to conduct – quality research.

Engineers often have to justify the significance of their work, defend the accuracy of their findings, and substantiate the soundness of the work's applicability to broader settings. The development of such skills takes place in group meetings. All 13 core group members were expected to attend the weekly group meetings unless they had a class that met at a conflicting time. The group meetings included general announcements, followed by two conference-style 20-minute presentations by group members. After each presentation, Professor Houston opened the floor for 15 minutes of constructive criticism during which members offered the presenter feedback on content, delivery, and other substantive issues. Presentations regularly went over the allotted time as group members provided constructive criticism to presenters. Each member presented research at a group meeting three to four times per semester.

Unlike the weekly group meetings where the emphasis was on students' oral presentation skills, weekly subgroup meetings allowed Houston members to receive consistent feedback on their work in progress. At these smaller meetings, where members were grouped by their research projects, students described their activities and progress during the previous week one by one. Briefings typically included two to three

PowerPoint slides. Sherman, a second-year doctoral student, stated: “[At] subgroup meetings you come in and give maybe a 5- to 10-minute presentation on what you’ve been working on for that week, and there is some give and take.” He further explained that giving briefings on one’s work at subgroup meetings helped to “keep yourself in check to make sure that you have done something that week.” Whereas the group meetings were about presenting one’s good and/or compelling results, in subgroup meetings, members admitted to their current difficulties in efforts to garner help.

Through these meeting practices, students learned four dominant research competencies: 1) presenting research; 2) receiving and responding to feedback; 3) solving problems; and, 4) troubleshooting problems. Table 2 below includes definitions of these competencies.

Table 2: Students’ Research Practices and Competencies Learned*

Research Practice	Learned Competency	Definition of Research Competency
Group Meetings	Presenting Research	Explaining one’s research in accessible ways to a broad audience
Group Meetings	Receiving and Responding to Feedback	Giving, receiving, and responding to criticism related to one’s research
Group Meetings and Lab	Solving Problems	Implementing an overall strategy that guides the group’s research
Group and Subgroup Meetings, Lab	Troubleshooting Problems	Iteratively (and sometimes collaboratively) working through day-to-day problems encountered in ongoing research projects

* The competencies and their definitions are synthesized from the full data set.

Presenting Research

The composition of the Houston Group (i.e., chemical engineers; chemists, mechanical engineers) provided students with opportunities to practice describing their research in accessible ways to wide audiences. The development of this competency took

place during full group meetings, and appeared to be in preparation for future dissemination to academic and industry audiences.

There was no required format for structuring one's research talk for group meetings, but because students presented regularly, it was understood that they would address "what you are doing, where you are at, what did you find, what have you been working on, [and] what challenges did you encounter...your result [however] is what is most important," (Allen). Allen, a second-year doctoral student, explained that at minimum, presenters discussed the motivation [i.e., the problem], a brief literature review with few references, their research design and their results. These conventions about framing one's presentation, as well as what to include and exclude, were not written down; students – particularly those new to the group – learned how to present by watching the senior student members present and receive corrective feedback each week.

Erik, also a second-year doctoral student, discussed how he learned to describe his research during group meetings and the benefits of participating in this practice: "[P]art of the research experience is growing in a sense of learning how to present things and learning how to do research...[presenting in front of Professor Houston] is a good thing. That leads to you being careful, leads you to thinking of questions he's [Professor Houston] going to ask in advance." Learning to present and improving one's capacity to describe research to a wide audience were goals of presenting at group meetings. Because presenting in group meetings was such a dominant practice of the Houston Group, Erik related his research experiences to his developing presentation competency.

Notwithstanding the nervousness that comes with presenting one's work, particularly in front of the faculty advisor "who knows so much more than you do," Erik noted other

benefits to presenting one's work in the Houston Group: students became more thoughtful about what they presented and anticipated future questions.

Receiving and Responding to Feedback

In the Houston Group, part of learning how to describe one's research included receiving and responding to feedback and learning to disagree. Learning this competency was not about learning to "argue"; rather, it was about learning how to justify one's claims, and anticipate future challenges to one's work. Related to this study, scholars suggest that "argumentation" (Cho and Jonassen, 2002; Tonso, 2014) and "justification" (Shin *et al.*, 2003) – synonymously used in existing literature – are necessary to develop communication and reasoning skills needed to address problem solving in STEM fields. Cho and Jonassen (2002) define argumentation as "the process of making claims and providing justification for the claims using evidence," (p. 5). They argue that classroom instruction – and/or face-to-face instruction – does not conclusively improve students' abilities to develop and defend sound arguments. However, they found that scaffolding problem-solving skill development and argumentation was successful with an undergraduate population; students who engaged in group problem-solving activities were better able to make cohesive arguments and offer rebuttals after computer-based scaffolding. While Cho and Jonassen's study was based on undergraduates and computer-simulated scaffolding, their findings suggest that intentional scaffolding by faculty and practice in argumentation might improve doctoral students' problem-solving skills. Their findings also suggest that developing those skills requires both practice and mediation of some sort (e.g., software, peers, faculty) to help students acquire them.

When describing the role he played during group meetings, Professor Houston explained that he intentionally scaffolded the feedback portion of presentations. He shared that he preferred to have students or the post-doc ask questions of presenters, but he first asked “a leading question” that “will force you to think about things.” He also questioned presenters during these meetings because he wanted to model for students in the audience the habit of asking questions, as much as he wanted presenters to build their skills in justifying their claims. The types of questions that Professor Houston asked were consistent: why a particular method was used, why certain steps were taken (i.e., protocol), what the literature (including past work by Houston Group alums) said about the findings. Priming presenters with questions and focusing on certain kinds of questions each week highlighted a pattern of the kinds of information he felt made presentations and research strong. Professor Houston believed that his facilitation of the feedback portion of meetings mediated students’ learning about research and their becoming scientists.

As a result of Professor Houston’s attempts at scaffolding students’ learning about research and argumentation, the sessions in which students received and responded to feedback were often contentious. Professor Houston acknowledged that “we battle, battle, battle,” referring to the intense nature of the question-and-answer portion of group meetings. He explained that he incorporated constructive criticism into the group’s practices because as an established faculty member, he, too, still received this kind of feedback and it helped him continue to grow: “Criticism is an important part of growing and learning, and it’s tough to take. Maybe as a faculty member, you submit proposals – and you think it’s the greatest thing [sic]; the odds are it’s going to be rejected. There’s a

one-in-ten chance that you are going to be successful with that proposal. So I've gotten used to being criticized." Because Professor Houston saw value in critique, he believed dealing with criticism was an important competency for his students.

In the excerpt below, a scene from a full group meeting highlights the social practices of receiving and responding to feedback. This exchange involved a disagreement between Allen and a more senior student, Brielle, as she prepared for her dissertation proposal defense:

Fieldnotes Excerpt 1 (Month 3):

Brielle is going to present today. This time, she is preparing for her upcoming dissertation proposal defense. This meeting is important in the Chemical Engineering Department; once students pass this proposal hearing, they can officially begin working on their dissertation.

During her presentation, Allen starts to relentlessly challenge Brielle. Although Allen is the less senior of the two – by three years – he continues to challenge her conceptualization and application of the word “stabilization” in her literature review. In order to get the practice presentation back on track, Professor Houston sides with Brielle and tries to explain to Allen that one can differently present research to practitioners than academicians, based on the intended audience.

Not willing to concede, Allen continues to challenge Brielle's usage of the word, now citing her conceptualization relative to literature he has recently reviewed. It is apparent that he and Professor Houston disagree; Professor Houston says to Allen, “I know you think you're right...” and Allen jumps in and says, “I am right!” They do that back-and-forth dance one more time until Professor Houston calmly stops and describes one final time the differences between academics in engineering and practitioners. Perhaps realizing that it is not his battle to win, Professor Houston stops engaging in the argument when he realizes that he was responding for Brielle instead of allowing her to respond to the feedback and disagreement.

Back in control...Brielle strongly stands by her use of the term “stability,” loses her usual calm, cool, demeanor, and becomes defensive, exasperatedly retorting, “Why would I do that [change the use of her word], what's the problem?” Her response has more bite to it, her tone is harsher, she's talking faster, and is much more combative.

The exchange between Brielle and Allen comes to an awkward halt as Professor Houston intervenes – after allowing it to play out for a while. This time, however, Professor Houston sides with Allen by saying to Brielle in a calm tone, “That’s not a defensible response,” referring to her harsh retort to Allen.

In the excerpt above, Professor Houston allowed Brielle to engage substantially with Allen before he finally played mediator and reminded her that she did not have to agree with Allen’s perspective, but that she could not raise her voice at audience members who disagreed with her work. In doing so, Professor Houston was emphasizing through this teachable moment the importance of remaining calm, listening to someone’s question, then respectfully responding.

The practice of receiving and responding to feedback is challenging for students. The scene described above during a group meeting presentation was not uncommon; examples of teaching moments occurred so often during the group meetings that Houston team members had a running quote that operated like a group philosophy: “If you can make it out of here [the group meeting], then you can make it anywhere.” This quote and sentiment – usually only referenced in the context of a group meeting presentation – was often invoked after a student survived an extended session justifying his or her work in front of the faculty advisor and student group members, like Brielle in the scene described above. In Brielle’s high-stakes practice presentation, in particular, Professor Houston explained to the group that successfully passing one’s dissertation proposal defense could hinge on one’s ability to appropriately respond to feedback.

Exchanging feedback and responding to disagreements helped students learn what were – and how to make – justifiable and persuasive arguments, further helping them develop expertise in their research area and in the competency of presenting. Despite the

harshness of the process, each student in this study described the development of this skill as necessary for conducting and presenting solid research.

Solving Problems

There is consensus that problem solving is what engineers do and that students need “experiential” hands-on practice – rather than classroom and textbook simulations – to develop this skill. When engineers are hired they are expected to identify and solve problems (Jonassen, 2014), which requires understanding not only engineering concepts, but also professional standards, and potentially, ethics as well (Jonassen and Hung, 2006). Because experiential practice in problem solving – at the undergraduate and graduate levels – prepares students for the types of work they will do upon entering the workforce (Jonassen and Hung, 2006; Shin *et al.*, 2003), problem solving is one of the most important competencies for engineering graduates.

In the current study, problem solving relates to the development of an overall strategy to guide the group’s work. It appeared to be one of the central competencies germane to learning about research and how to be an engineer. Student group members engaged in addressing the larger “problems” of improving battery efficiency, which relates to the goals of identifying and utilizing sustainable and alternative energy sources. Many in the Houston Group understood the importance of the problem-solving competency within their group context and within the larger field of engineering. Danny, an advanced doctoral student, suggested that “the whole field [of engineering] is problem solving and it's the way you think about problems and how you approach problems.” He asserted that those who have difficulty in engineering are those who cannot solve

challenging problems. Later, he expressed his view of problem solving as a scientific and technical competency that was developed over time:

[Y]our first year, you're given a problem and you think "oh this can be solved" because I'm used to solving problems from the book and a lot of them are solvable. But you begin to see reality of what the real thing is and you have to evolve so that you can actually deal with the reality of "some of the problems are not very practical as you can see from the book." So the whole perspective changes and you begin to see the fuller picture of how science and engineering works. (Danny)

Danny contended that competence in problem solving is not mastered after a year of research experiences. The research process is arduous and may include many missteps and failed experiments. It appeared that the research experiences in the Houston Group provided opportunities for experimentation, failure, and the growth of this competency.

Troubleshooting Problems

Unlike problem solving, which refers to the “big picture” strategy that guides a group’s research work, troubleshooting focuses on iteratively attending to the day-to-day problems encountered in ongoing research projects and experiments. In both the full group and subgroup contexts, troubleshooting was intended to achieve similar outcomes: to demonstrate students’ research progress and ensure that students produced credible work. Activities within this competency were determined to include interrogating literature, considering societal issues, running experiments, and analyzing data because these were the operational tactics students used in the everyday conduct of their research,

and were consistent with other scholars' conceptualizations of "troubleshooting" (see for example Jonassen, 2000 and 2014, and Jonassen and Hung, 2006).

To troubleshoot, individuals must have various forms of domain knowledge (e.g., engineering properties), system or device knowledge, procedural knowledge (to be able to perform diagnostic tests), and strategic knowledge to iteratively search for potential solutions (Jonassen and Hung, 2006). Jonassen and Hung (2006) state that the cognitive process of troubleshooting illustrates a "shift from conceptual understanding of the system to an experiential understanding of the process" (p. 189). Differentiating between conceptual and experiential understanding is important because several scholars have criticized students' abilities to problem solve (Jonassen, 2014; Jonassen and Hung, 2006; Shin *et al.*, 2003), particularly because faculty in engineering classrooms tend to present "well-structured" problems that are formulaic and solved easily (Jonassen, 2014).

In the present study, troubleshooting occasionally occurred when student presenters made consistent mistakes, for example, when Professor Houston noticed an underlying error in methodology or experimentation. He would then intervene, breaking the traditional presentation structure to help a student work through the mistake, so that other students could learn from the presenter's error and avoid similar ones. In other instances, when students ran into problems associated with their individual research projects that they could not figure out on their own, they brought their issues to the subgroup meetings where others could suggest ways to address the problem. In subgroup meetings, students were encouraged to admit when they did not know something, because in this context, fellow subgroup members were expected to help each other resolve issues. The intimate nature of the subgroup meeting promoted greater interaction (i.e.,

mediation) among students, highlighting a key contrast with troubleshooting in the group meeting.

During one subgroup meeting in the fourth month of data collection, the researcher observed members engaged in troubleshooting. The meeting on this day was typical in that students went around the room trying to help fellow subgroup members troubleshoot challenges they had encountered in their research. One student in particular, Tiffany (a third-year doctoral student), became the central focus because of her persistent concerns about her equipment and the findings she was presenting.

Fieldnote Excerpt 2 (Month 4):

Tiffany begins giving her update. Unlike the other students, Tiffany is taking quite a bit of time talking about her research. Because this subgroup is small (seven people), and significantly smaller than the regular group meeting, time is being used to troubleshoot her issues, rather than “grilling” her with questions like at a group meeting. During an impasse of suggestions, Gloria gets up from her seat to go to the white erase board to draw a suggestion for how Tiffany can fix her equipment to provide better results during the next run of her experiment.

After approximately 15-20 minutes spent on Tiffany’s research issues, Professor Houston jumps in to make sure that the meeting is still moving. He suggests that since the group assumes there is a design flaw with her equipment, the subgroup members should examine her equipment in the lab after three final subgroup members give their research updates.

Drawing on the work of other scholars, Jonassen and Hung (2006) describe several common troubleshooting strategies. The scene described above is similar to the “topographic” strategy whereby potential faults are isolated after engaging in a series of diagnostic checks. When Tiffany bravely explained where she was having trouble with her results, group members collectively attempted to identify potential pitfalls in her research design and pitched possible solutions to help her redesign the equipment. When no clear answers resulted, Professor Houston decided the group would better serve

Tiffany if they examined and fixed her equipment directly since they had already speculated during the meeting that her issues lay in the design of the equipment.

Houston student group members sometimes equated doing “good research” with their abilities to troubleshoot problems in their individual research, likely because students were required to identify and address problems at subgroup and full team meetings. For instance, Emma, a Houston Group alum and now post-doctoral student in the group, expressed confidence in her ability to do good research because of her ability to troubleshoot. For her, troubleshooting related to “thinking of possibilities,” and then thinking of experiments needed to “prove a hypothesis.” Emma’s views were consistent with those of other group members.

DISCUSSION

Central goals of this article were to identify the competencies learned by engineering doctoral students participating in research group experiences, and to better understand the practices and activities that facilitate students’ learning around these competencies. An additional goal was to provide a detailed discussion, within the domain-specific context of engineering, to contribute to the broader discourse on learning within graduate education. Because of the emphasis on students’ learning, a sociocultural perspective on learning , which offers key concepts of context, mediation (e.g., interactions), and participation, was used as a theoretical frame to guide understandings of how a research group, as a context for teaching and learning, can be considered a community of practice.

As suggested by the findings, students’ learning and development within the Houston Group were influenced by several broader contexts: demands for new

knowledge from the engineering field, and institution, college, and department expectations of research productivity at a premiere research university. These nested contexts are necessary to consider because the practices and activities of the Houston Research Group were implemented, at least in part, as a result of the demands stemming from the broader contexts. For example, the decision by Professor Houston to hold weekly subgroup meetings where students would provide status updates on their independent projects and collectively troubleshoot issues was made to maximize efficiency and increase research productivity.

Students' class status was distributed throughout the group, highlighting the steady progression from novice researchers to more senior group members. This is important to note because while students were interdependently-independent (meaning that while they often worked individually during the day, much of their research – and learning about research – built on the knowledge and mediation of other students in the subgroup), members had to collaborate with and learn from each other in order to access the tools and apply the skills needed to complete their individual portion of Professor Houston's larger program of research. Social learning as a form of mediation is not unique to the Houston Research Group. As explained by Villa *et al.* (2013), "members cross-train on each other's areas of expertise in order to expand participants' expertise and to ensure the group's continuation as members graduate and leave the group" (p. 462). Similarly, work by Baker and Pifer (2011) and Baker, Pifer, and Flemion (2013) highlights the significant roles social networks play in doctoral students' learning and professional identity development, peers being one of the significant social networks found in their study. Mediation within the Houston Group took place within all of the

group's practices and activities. The interactive nature of the group facilitated an environment where students were expected to regularly communicate with one another to complete research tasks. Expanding on the full group meeting example in the findings above, after most full group meetings where students presented their work in progress, group members routinely provided additional support and feedback to presenters.

Finally, participation in the group's activities was ongoing as newcomers and more senior members attempted to master their research competencies. For instance, in excerpt #1, Allen was honing his skills of providing feedback to Brielle, while Brielle was developing her competencies in presenting and responding to feedback. In both cases, Allen and Brielle were participating in the research-related practices and activities of the Houston Group. While these competencies were not yet fully mastered (as indicated by Professor Houston stepping into their exchange and using the exchange as a teachable moment), their engagement in these practices and activities were early demonstrations of where they were in their learning and development.

The aggregated list of members' learning by research practice (in Table 2) should not be considered exhaustive; it is highly likely that members learned more competencies (and learned from other research practices that were not identified in this study). Regardless, it is important to acknowledge the role of group meetings in students' learning of research competencies. The evidence from this study suggests that group meetings hold significant value in helping group members learn how to be effective researchers. Members learn both by participating in the research practices (for example, giving presentations) and by interacting with others (for example, watching another member present research, then providing constructive feedback on their work, and

listening to the research supervisor offer feedback). Thus, the group meeting as a social location is important, and the practices themselves are equally important to *what* research competencies students learn and *how* they learn them. Based on these findings, Table 3 provides implications for research group mediation and participation based on the research practices identified in this article.

Table 3: Implications for Research Group Mediation and Participation by Research Practice

Research Practices	Key Components of these Practices	Implications for Research Group Mediation and Participation
Group Meetings	Weekly, generalized feedback on one's body of work, learning through presenting and through observation of peers' presentations and feedback	<ul style="list-style-type: none"> - Schedule regularly - Distinguish type of presentation in the group meeting from the subgroup meeting; the group meeting presentation should present one's body of work - Because learning takes place through both presentations and observations of presenters (and the feedback provided thereafter), allow adequate time for questions and answers after presentations
Subgroup Meetings	Weekly, smaller group format, in-the-moment guidance and support, scaffolded learning	<ul style="list-style-type: none"> - Keep subgroups small to provide students with enough support and prevent them from feeling invisible or becoming lost - Schedule regularly with the understanding that students will encounter more challenges in their research that need to be resolved before they are able to present in front of the big group - Make weekly updates low-stakes (i.e., less pressure on perfection, and more on learning from mistakes) because members will be presenting difficulties they encounter during the week
Lab Work	Primarily independent work, collaborative via equipment, peers available for support, leadership team available for support only after members have consulted peers	<ul style="list-style-type: none"> - Design infrastructure where more senior group members help train newer group members to use the lab equipment because using it to conduct one's experiment is key to working independently in the lab - Encourage members on related projects or using similar equipment to schedule lab hours around the same time so they can address questions about equipment

Another goal of this study was to extend the base of knowledge about engineering graduate education, specifically about the influence of research group experiences on graduate student learning. Several implications are offered below as research propositions (i.e., hypotheses) for future testing.

Proposition 1

The practices and activities of a research group influence the development of particular kinds of research competencies. But demonstrated competence may not reflect an overall proficiency in research skills, or translate to other research tasks.

The data in this study highlight the important role troubleshooting plays in the research experiences of Houston Group student members. In most scenarios, Professor Houston posed questions and engaged in teachable moments during group meetings so that non-presenters would learn (e.g., presentation styles, research techniques) from presenters' mistakes. It appeared as if he was publicly troubleshooting with presenters to help other students avoid similar problems. Despite his efforts, some of the same problems continued to occur, which might suggest that, as described by Jonassen (2014), troubleshooting is task-specific (i.e., an individual may learn how to complete a specific project-related task, and not be able to troubleshoot a new task that arises from a different project), and individual-specific (i.e., an individual's learning of a specific task does not necessarily lead to transfer of learning to other students). In addition, the ways troubleshooting operated differed via the group and subgroup contexts, and shaped the interactions students had with each other around this competency. This, too, might suggest that specific practices and activities, within certain bounded contexts, lead to distinct forms of learning (i.e., research competencies).

Proposition 2A

The faculty advisor – and how the advisor structures the practices and activities of the research group – in part influences what research competencies students develop and how they develop them.

It is clear from this study that research supervisors shape student learning about research. Like syllabi, research supervisors can design research experiences with learning outcomes in mind. In a study of graduate students in STEM, Feldon, Shukla, and Maher (2016) found that students who co-authored manuscripts with faculty members reported higher levels of research skills than students who did not have similar experiences. In the present study Professor Houston and the leadership team were thoughtful about developing students' research competencies when considering the group's organizational structure, composition, and practices and activities. Future research should explore how the design of a research group, and its practices and activities, influence students' learning of research.

Proposition 2B

The faculty advisor – and how the advisor mediates students' learning of particular competencies – influences how students perceive their learning.

Despite discomfort with the experience of presenting, all students described learning from the process of argumentation. In fact, students' confidence in presenting and doing research was related to their ability to defend their methods and ideas, and equally important, withstand "grilling." It appeared that students' learning was mediated by Professor Houston's scaffolding, which highlighted the importance of feedback and disagreement in the research group – and implicitly the engineering field. Professor Houston's scaffolding around argumentation and presentation may not be representative

of how other engineering faculty members prime students for public presentations. It suggests, however, that when this process is not well facilitated, and students do not understand the learning behind the process of argumentation, they may misconstrue “grilling” as evidence of a “chilly,” “isolating,” “competitive,” and “hostile” climate, which is well documented in the literature on why students (especially women and students of color) leave STEM fields (Burt *et al.*, 2016; Feldon *et al.*, 2015; Fries-Britt, Burt, and Franklin, 2012; Gasman *et al.*, 2009; Green and Glasson, 2009; Sowell, Allum, and Okahana, 2014).

CONCLUSION

It is widely accepted that engineering graduate education prepares students for the STEM workforce by equipping them with particular kinds of research skills. For example, it is commonly believed that graduate students in research group experiences learn research competencies that help them participate in scholarly activities. However, empirical and theoretically-based details about the specific skills students learn, helpful information about the educational contexts in which student learning occurs, and strategies for the facilitation of learning by faculty and other individuals within students’ educational contexts are scarce in the existing literature. By addressing the propositions for future research, scholars can begin to more deeply understand and fill the gaps regarding what students are *learning* at the graduate level in engineering.

REFERENCES

- Antony, J. S. and Taylor E. (2001), "Graduate student socialization and its implications for the recruitment of African American education faculty", in Tierney, W.G. (Ed.), *Faculty Work in Schools of Education: Rethinking Roles and Rewards for the Twenty-First Century*, SUNY Press, Albany, NY, pp. 189-209.
- Austin, A. E. (2009), "Cognitive apprenticeship theory and its implications for doctoral education: a case example from a doctoral program in higher and adult education", *International Journal for Academic Development*, Vol. 14 No. 3, pp. 173-183.
- Austin, A. E. (2002), "Preparing the next generations of faculty: graduate school as socialization to the academic career", *Journal of Higher Education*, Vol. 73 No. 1, pp. 94-122.
- Baker, V. L., and Lattuca, L. R. (2010). "Developmental networks and learning: Toward an interdisciplinary perspective on identity development during doctoral study", *Studies in Higher Education*, Vol. 35 No. 7, pp. 807-852.
- Baker, V. L., and Pifer, M. J. (2011). "The role of relationships in the transition from doctoral student to independent scholar". *Studies in Continuing Education*, Vol. 33 No. 1, pp. 5-17.
- Baker, V. L., Pifer, M.J. and Flemion, B. (2013), "Process challenges and learning-based interactions in stage 2 of doctoral education: implications from two applied social science fields", *Journal of Higher Education*, Vol. 84 No. 4, pp. 449-476.
- Bhattacharyya, G. and Bodner, G. M. (2014), "Culturing reality: how organic chemistry graduate students develop into practitioners", *Journal of Research in Science Teaching*, Vol. 51 No. 6, pp. 694-713.
- Brown, J. S., Collins, A. and Duguid, P. (1989), "Situated cognition and the culture of learning", *Educational Researcher*, Vol. 18 No. 32, pp. 32-42.
- Burt, B. A. (2014), "The influence of doctoral research experiences on the pursuit of the engineering professoriate", Dissertation. University of Michigan.
- Burt, B. A., McKen, A. S., Burkhart, J., Hormell, J., and Knight, A. (2016). *Racial microaggressions within the advisor-advisee relationship: Implications for engineering research, policy, and practice*. American Society for Engineering Education (ASEE) conference proceeding.
- Cho, K. L. and Jonassen, D. H. (2002), "The effects of argumentation scaffolds on argumentation and problem solving", *Educational Technology Research and Development*, Vol. 50 No. 3, pp. 5-22.
- Collins, A., Brown, J. S. and Holum, A. (1991), "Cognitive apprenticeship: making things visible", *American Educator: The Professional Journal of the American Federation of Teachers*, Vol. 15 No. 3, pp. 6-11, 38-46.
- Corbin, J. and Strauss, A. (2008), *Basics of Qualitative Research: Techniques and Procedures for Developing Grounded Theory*, Sage Publication, Thousand Oaks, CA.
- Emerson, R. M., Fretz, R. I. and Shaw, L. L. (1995), *Writing Ethnographic Fieldnotes*, The University of Chicago Press, Chicago, IL.
- Felder, P. P., Stevenson, H. C., and Gasman, M. (2014). Understanding race in doctoral student socialization. *International Journal of Doctoral Studies*, Vol. 9, pp. 21-42.
- Feldon, D. F., Shukla, K. D., and Maher, M. A. (2016) Faculty–student coauthorship as a

- means to enhance STEM graduate students' research skills. *International Journal for Researcher Development*, Vol. 7, No. 2, pp.178 – 191.
- Feldon, D. F., Maher, M. A., Hurst, M., and Timmerman, B. (2015). Faculty mentors', graduate students', and performance-based assessments of students' research skill development. *American Educational Research Journal*, Vol. 52, No. 2, pp. 334-370.
- Fetterman, D. M. (2010), *Ethnography*, Sage Publications, Thousand Oaks, CA.
- Fries-Britt, S. R., Burt, B. A., and Franklin, K. (2012), "Establishing critical relationships: how Black males persist in physics at HBCUs", in Palmer, R.T. Palmer, and Wood, J.L. (Eds.) *Black Men in Black Colleges: Implications for Diversity, Recruitment, Support, and Retention*, Routledge, New York, NY, pp. 71-88.
- Gardner, S. K. (2007), "I Heard It through the grapevine: doctoral student socialization in chemistry and history", *Higher Education*, Vol. 54, pp. 723-740.
- Gardner, S. K. (2008), "'What's too much and what's too little?': the process of becoming an independent researcher in doctoral education", *Journal of Higher Education*, Vol. 79, pp. 326-350.
- Gardner, S. K. (2009), "The development of doctoral students: phases of challenge and support", *ASHE Higher Education Report*, Vol. 34 No. 6, pp. 1-127.
- Gasman, M., Perna, L. W., Yoon, S., Drezner, N. D., Lundy-Wagner, V., Bose, E. and Gary, S. (2009), "The path to graduate school in science and engineering for underrepresented students of color", in Howard-Hamilton, M.F., Morelon-Quainoo, C.L., Johnson, S.D., Winkle-Wagner, R., and Santiago, L., *Standing on the Outside Looking In: Underrepresented Students' Experiences in Advanced Degree Programs*, Stylus Publishing, Sterling, VA, pp. 63-81.
- Gildersleeve, R. E., Croom, N. N., and Vasquez, P. L. (2011): "Am I going crazy?!": A critical race analysis of doctoral education. *Equity & Excellence in Education*, Vol. 44, No. 1, pp. 93-114.
- Golde, C. M. (2005), "The Role of the department and discipline in doctoral student attrition: lessons from four departments", *Journal of Higher Education*, Vol. 76 No. 6, pp. 669-700.
- Green, A. and Glasson, G. (2009), "African Americans majoring in science at predominantly White universities (A review of the literature)", *College Student Journal*, Vol. 43 No. 2, pp. 366-374.
- Holley, K. (2009), "Animal research practices and doctoral student identity development in a scientific community", *Studies in Higher Education*, Vol. 34 no. 5, pp. 577-591.
- Holley, K. (2011), "A cultural repertoire of practices in doctoral education", *International Journal of Doctoral Studies*, Vol. 6, pp. 79-94.
- Jonassen, D. H. (2014), "Engineers as problem solvers", in Johri, A. and Olds B.M. (Eds.), *Cambridge Handbook of Engineering Education Research*, Cambridge University Press, New York, NY, pp. 103-118.
- Jonassen, D. H. (2000), "Toward a design theory of problem solving", *Educational Technology: Research and Development*, Vol. 48 No. 4, pp. 63-85.
- Jonassen, D. H. and Hung, W. (2006), "Learning to troubleshoot: a new theory-based design architecture", *Educational Psychology Review*, Vol. 18 No. 1, pp. 77-114.

- Lave, J. and Wenger, E. (1991), *Situated Learning: Legitimate Peripheral Participation*, Cambridge University Press, New York, NY.
- Lindholm, L. A. (2004). "Pathways to the professoriate: The role of self, others, and environment in shaping academic career aspirations", *Journal of Higher Education*, Vol. 75 No. 6, pp.603-635.
- Merriam, S. B. (2009), *Qualitative Research: A Guide to Design and Implementation*, Jossey-Bass, San Francisco, CA.
- Rogoff, B. (1990), *Apprenticeship in Thinking: Cognitive Development in Social Context*, Oxford University Press, New York, NY.
- Sallee, M. W. (2011) "Performing masculinity: considering gender in doctoral student socialization", *Journal of Higher Education*, Vol. 82 No. 2, pp. 187-216.
- (Baker) Sweitzer, V. (2009). "Towards a theory of doctoral student professional identity development: A developmental networks approach", *The Journal of Higher Education*, Vol. 80 No. 1, pp. 1-33.
- Shin, N., Jonassen, D. H. and McGee, S. (2003), "Predictors of well-structured and ill-structure problem solving in an astronomy simulation", *Journal of Research in Science Teaching*, Vol. 40 No. 1, pp. 6-33.
- Sowell, R., Allum, J., and Okahana, H. (2015). *Doctoral initiative on minority attrition and completion* (DIMAC Report), Council of Graduate Schools, Washington, DC.
- Spradley, J. P. (1979). *The Ethnographic Interview*. Harcourt College Publishers, Fort Worth, Texas.
- Tierney, W. G. (1997), "Organizational socialization in higher education", *The Journal of Higher Education*, Vol. 68, pp. 1-16.
- Tonso, K. L. (2014). "Engineering identity", In A. Johri, B. M. Olds (Eds.) *Cambridge Handbook of Engineering Education Research*,. Cambridge University Press, New York, pp. 267-282.
- Van Maanen, J. M. (1988), *Tales of the Field: On Writing Ethnography*, The University of Chicago Press, Chicago, IL.
- Vekkaila, J., Pyhältö, K., Hakkarainen, K., Keskinen, J. and Lonka, K. (2012), "Doctoral students' key learning experiences in the natural sciences", *International Journal for Researcher Development*, Vol. 3 No. 2, pp. 154-183.
- Villa, E. Q., Kephart, K., Gates, A. Q., Thiry, H. and Hug, S. (2013), "Affinity research groups in practice: apprenticing students in research", *Journal of Engineering Education*, Vol. 102 No. 3, pp. 444-466.
- Weidman, J. C. and Stein, E. L. (2003), "Socialization of doctoral students to academic Norms", *Research in Higher Education*, Vol. 44, pp. 641-656.
- Weidman, J. C., Twale, D. J. and Stein, E. L. (2001), "Socialization of graduate and professional students in higher education: A perilous passage?", *ASHE-ERIC Higher Education Report*, Vol. 28 No. 3, pp. 1-138.
- Wenger, E. (2010), "Communities of practice and social learning systems: the career of a concept", in Blackmore, C. (Ed.), *Social Learning Systems and Communities of Practice*. Springer Verlag and the Open University, pp. 179-198.
- Wertsch, J. V., del Rio, P. and Alvarez, A. (1995), "Sociocultural studies: history, action, and mediation", in Wertsch, J.V., del Rio, P. and Alvarez, A., *Sociocultural Studies of Mind*, Cambridge University Press, New York, NY, pp. 1-34.

Wolcott, H. F. (1994), *Transforming Qualitative Data*, Sage Publications, Thousand Oaks, CA.

Wortham, S. (2004), "The interdependence of social identification and learning", *American Educational Research Journal*, Vol. 41 No. 3, pp. 715-750.