Work in Progress: Qualitative Differences in Learning Processes and Skill Development Across Engineering Capstone Teams

Abstract

This work in progress paper presents a study that follows four engineering capstone teams over the course of their two-year projects. Students on four different teams collected ethnographic and autoethnographic data in the form of field notes to explore how students learn across a variety of projects that vary in their scope, type, and team composition. This paper aims to explain the impacts that role rigidity and project management style have on the design process and discuss the factors that influence the types of learning occurring in capstone teams. Data suggest that project scope, role rigidity, and the level of ambiguity in the project impact the learning processes employed by different teams, and the skills that team members developed.

1 Introduction

This work in progress study uses ethnographic and collaborative autoethnographic methods to track four different undergraduate engineering capstone teams over the course of their two-year capstone projects to describe the qualitative differences in observed learning processes and skill development between teams with varying project scope, making foci, and complexity of team roles. The capstone projects address a variety of engineering topics ranging from renewable energy and smart sensing technology. During the first year of the capstone project, four undergraduate researchers used autoethnographic methodologies to track their own experiences as members on their respective capstone teams and developed reflexive field notes on behaviors, affect, and learning experiences during the formative phase of their group's development. Using iterative processes of qualitative data analysis, the research team, which includes four undergraduate engineering students, a graduate communication student, an engineering professor, and a communication professor, identified the central issues related to learning, project scope, and group role complexity that guide later data collection for this project. During the second year, the research team collects additional autoethnographic and ethnographic data to refine their examination of learning processes across different team structures.

The researchers analyze the data using the iterative methods of constant comparison to identify the comparative experiences of learning observed across the four groups [1] [2]. The study of bona fide groups such as these, rather than zero-history groups, is particularly valuable toward enhancing the transferability of the research findings and understanding the dynamic and complex interfaces of these groups within the larger organizational environment of the university and engineering department [3]. This paper will discuss learning experiences in the following ways: Roles develop organically based on interpersonal skills and expertise and the conditions and demands of the teams; Project scope and definition along with team size and composition

determine the rigidity of roles students occupy; Role rigidity impacts what skills team members develop in the course of their project.

2 Background

2.1 Team Composition and Task Effectiveness

The literature on project groups suggests that team composition can impact team performance and learning processes in a number of ways. Gender, personality, interpersonal skills, among other characteristics have been found to affect the processes of engineering teams [4][5][6][7]. While there is extensive research on the impact of personality on team performance and effectiveness, one of the most widely accepted descriptors of personality of groups is the "Big Five" [5]. These five traits are extroversion, agreeableness, conscientiousness, emotional stability/neuroticism, and openness to new ideas [6]. However, conscientiousness is the only trait that has been replicated as having a positive effect on team performance [5]. Additionally, when displayed as collective personality traits, openness to experience, extraversion, conscientiousness, and agreeableness were shown to positively relate to group interpersonal citizenship behavior [6]. Interpersonal citizenship behavior (ICB) occurs when members voluntarily help their teammates, which in turn can increase task effectiveness and members' willingness to continue to contribute to the team [6] [7].

The Big Five traits are typically applied to groups in aggregate, but there are a number of other interpersonal skills than can have a positive impact on team performance and processes [8]. One such trait is emotional intelligence (EI). High levels of emotional intelligence among team members, team leaders, or both have been shown to positively correlate to higher team performance [9]. It is likely that this increased team performance is a result of members being able to devote more brainpower to important tasks, rather than expending energy on regulating affective atmospheres [9]. Similarly, many teams can suffer from high transaction costs, which occur when time is spent on non-task-related processes, such as communicating ideas and coordinating activities [10].

Team size can also impact transaction costs, as larger teams may have to spend more time scheduling meetings, creating and communicating about meeting agendas, and more [10]. Men also tended to be more controlling and competitive, and less concerned about women participating as the open-endedness of design problems increased [9]. Conversely, for a variety of reasons women felt an increased sense of difficulty as design problem open-endedness increased [9]. Not surprisingly, these gender differences can also affect the roles taken on by team members. It is relatively uncommon that formal roles are assigned in project-based learning environments, but it has been shown that teams with an imposed role structure tend to fair better than teams with no structure [10]. Specifically, Mennecke found that project groups with

imposed structure had better cohesion and finished their semester projects with a higher quality than teams without structure, although both types of team still suffered from social loafing and procrastination [10].

2.2 Situated Learning

This study is grounded in the theoretical framework of situated learning. Situated learning theory begins with the premise that learning happens through everyday practice, in particular contexts – *learning is a social activity* [11]. Contu and Willmott argue, "the promise of situated learning theory is to focus attention directly upon learning as a pervasive, embodied activity involving the acquisition, maintenance, and transformation of knowledge through processes of social interaction" [12]. Lave & Wenger center learning as embodied within an actor's lived experiences, as actors negotiate meaning with others and actively shape their identities and membership in a community [11, 13]. Such groups that share a common domain (such as engineering), interact regularly in order to build relationships and learn from one another, and practice aspects of that shared domain are known as *communities of practice* [11]. Communities of practice are bound together by their *joint enterprise*, *mutual engagement*, and *shared repertoire of communal resources* [14].

Wenger argues that the concept of identity is critically connected to our understanding of practice [15]. He argues that our identities are understood in a variety of ways in relationship to practice. For example, Wenger describes that identities can be defined as *negotiated in relationship with others*, as *community membership*, and as *a learning trajectory*, among others [16]. Such intersections between identity and the practice involved in engineering communities are key to understanding how and what learning is happening, particularly in our engineering curriculum. Thus, examining the practices of learning *in situ* has much to offer in our understanding of team-based learning curriculum as students seek to work competently together toward meeting a particular goal.

Grounded in Lave and Wenger's concept of communities of practice, Tomko's [17] study of women's learning in makerspaces advanced a valuable framework that can be applied to other communities of practice, such as engineering capstone teams. In her grounded theory, she identified a typology of learning processes and practices that emerge as students become members of a making community of practice. The typology includes the two learning processes of (1) learning by doing and (2) learning through others; the learning of skills of: (1) design process, (2) design terminology, (3) design tools, (4) design project, (5) design intuition, (6) attributes and culture of makerspaces, and (7) attributes related to characteristics and skills gained by individuals. Tomko's learning typology offers a heuristic framework for exploring the qualitative different experiences of learning across engineering capstone teams that vary in their composition and project demands.

2.3 Research Questions

To focus data collection sourced from four case studies, two research questions were asked. These research questions were explored throughout the analysis process of the data collected.

1. What are the ways in which role development and project management style are shaped by project scope and ambiguity in a two-year capstone project?
2. What are the qualitative differences in the learning processes and skills developed by team members on projects that vary by scope and ambiguity?

3 Methodology

This study uses methodologies of collaborative autoethnography [18] in which four undergraduate engineering students adopted the roles of "complete member" as well as researcher in exploring the team dynamics and learning processes in four different senior capstone teams. Chang et al. [18] define collaborative autoethnography as "a qualitative research method in which researchers work in community to collect their autobiographical materials and to analyze and interpret their data collectively to gain meaningful understanding of sociocultural phenomena reflected in their autobiographical data" [p. 23-4]. Over a period of two-years, student autoethnographers at a large public undergraduate university in the south traced their experiences on their capstone teams and collected data in the form of field notes containing both descriptive observations as well as interpretations of meaning [19]. All four engineering students are members of the same engineering cohort and are working toward completing the requirements of a Bachelor of Science degree in engineering which includes the completion of a two-year engineering capstone project. Field notes were created during and following engineering capstone meetings by the students, and all four students are on different engineering capstone projects. Following the characteristics of collaborative autoethnography, the student autoethnographers alongside faculty research team members worked together in an iterative fashion over the course of the two-year study to interpret emerging data and identify a focus on team dynamics as they impact student learning.

First, following an initial data immersion phase [20] in which the student researchers carefully examined the complete set of fieldnotes across the four teams four distinct cases where identified based on the project types and role development over the course of the project: *Entrepreneurial Scope with Fluid Roles and High Ambiguity*, *Entrepreneurial Scope with Organic Role Development, Product Redesign Scope with Assigned Roles,* and *Technology Focused Scope and Expert Roles.*

Second, the authors coded the data set to identify the processes and contents of learning using an *a priori* coding scheme by applying a pre-existing code book developed by Tomko [17]. Data were coded using the software package, N'Vivo 12 and the four cases were compared for the degree to which each case favored or weighted particular types of learning. Tomko's validated learning typology includes both the processes and contents of learning: learning by doing, learning through others, design process, design terminology, design tools, design project, design intuition, attributes and culture of capstone[1], and attributes related to characteristics and skills gained by individuals.

4 Current Results and Analysis

Each of the four capstone teams followed herein have varying types of project scope, role formation, and ambiguity, which is found to have impacted the types of learning that occurred in each team. *Case One* was characterized by fluid roles, high project ambiguity and an entrepreneurial scope. The team examined in *Case One* had just two members. *Case Two* also had an entrepreneurial scope, and roles developed organically. During the first year of the project, the team in *Case Two* had no formal roles, only adopting a more rigid structure in year two, once members' interests and skills had more clearly emerged. The team studied in *Case Two* had seven team members that were eventually divided into three sub-teams. The project in *Case Three* was a redesign project, and thus roles were assigned somewhat arbitrarily at the beginning of team formation, with the expectation that members would later develop the skills necessary to fulfill their designated role. *Case Three* featured seven team members divided into three sub-teams. *Case Four* was a technology-driven project with eight members. *Case Four* assigned roles based on expertise at the outset of the design process. Each of these cases and the learning processes therein are described in detail below.

4.1 Case One: Entrepreneurial Scope with Fluid Roles and High Ambiguity

Case One featured a capstone team with two members working on an entrepreneurial project with a high level of ambiguity. Team members were tasked with seeking out a problem in the local agricultural industry, connecting with a stakeholder, and then working through the design process to engineer a solution to the identified problem. With such an ambiguous project and small team size, members were required to take on a number of formal and informal roles, always having a hand in every aspect of the project. One team member described it this way:

> *It's also difficult this semester to delegate work. We can't have sub teams. We can't really divide and conquer. We both are involved in every aspect of the project. On the one hand, this is good because we both know about everything that's going on with the project. But on*

[1] In the original learning typology, the category was "attributes and culture of makerspaces." We modified this category to code for the attributes and culture of capstone.

the other hand, we aren't learning as much from each other… we can't research 5 things at once and then synthesize it. Instead, we're slowly but steadily learning alongside each other.

As described above, designating formal, rigid roles was nearly impossible on such a small team and with an open-ended project. As a result of these fluid roles, this team often experienced learning by doing and learning through others simultaneously. Because members worked so closely with one another, it was possible to learn not just from one's own practice and mistakes, but from the practice and mistakes of others. Members struggled to teach each other things directly, but as they worked "alongside each other", they weighted "learned by doing" over other forms of learning processes. Thus, they were able to pull each other along until each member had a baseline competence of every new skill.

Second, this group demonstrated comparatively greater "self-reflexivity" than the other teams required for successful progress on the project. Indeed, the ambiguous nature of this project necessitated a high amount of self-reflexivity, as members had to learn how to own and manage a project that was constantly being questioned by students and faculty alike:

People continue to ask me "how's the agriculture project going?" I don't mind this except for some reason I assume it's not because they're being polite and want to genuinely know how the project is going; I feel like they ask because they're expecting me to say it's going really bad or something; like people always sound a little surprised when I say it's going well... in front of my face the two [management] professors talked about how they didn't think my project should've been accepted.

Typically, capstone projects begin by first constructing a project management plan in conjunction with their required project management class. The project in case one, however, didn't lend itself well to the traditional management paradigms being taught in this course because at the beginning there was no identified client, no specific problem to solve, nor a specific technology to implement. Rather, the project was based on a belief that a design opportunity existed in a particular domain. This openness in scope presented the team with additional challenges and learning opportunities as members had to develop their own management style, given little formal instruction on how to do so.

4.2 Case Two: Entrepreneurial Scope with Organic Role Development

The team studied in case two was also an entrepreneurial project, with a moderate level of ambiguity. The goal of the project was to create something of value for an international stakeholder associated with a study abroad program sponsored by the engineering department. The project was proposed by two team members who participated in this program the summer

prior to their junior year, and this insider knowledge of the stakeholder, along with existing personal relationships, played a large role in the development of roles in the first year.

In fact, rather than assigning formal roles, a significant portion of the first year was spent trying to break out of the preconceived roles members had assigned to one another. One of the proposers of the project outright rejected being assigned the role of team leader in the team contract, saying *"One individual jumped to conclusion about the hierarchy scale of the team… I highly disagree with that."*

Members in case two had to learn how to take ownership of this project and develop roles despite the unequal distribution of knowledge at the outset of the project. Throughout the first year, team members who hadn't participated in the study abroad program often deferred all questions and leadership roles to the project proposers. Meanwhile, the proposers wanted nothing more than for their teammates to drop their preconceptions and participate fully:

> *Idk [I don't know] why but it is still feeling like it is my project…Always seems like they turn to me for too much…I have been very frustrated with some members for just not pulling their weight…May be going through the storming phase but I don't really think we are because nobody has acknowledged that…On the final presentation assignment is said every member should be able to answer questions. We knew that nobody other than us would have any idea what was going on. They would literally be learning it alongside the audience*

Not surprisingly, then, learning processes among members of case two is characterized by "learning through others," as they early team leaders imparted their direct knowledge of the stakeholder needs and requirements to the other team members, with the goal of creating flattened hierarchies in the management of the project itself.

Further, much of the learning that occurred in the first year was centered around the development of "interpersonal skills," as a team comprised of friends and strangers, experts and novices, had to navigate role and task delegation. This changed coming into the second year, after more members participated in the study abroad program, thus building new project expertise, and thus the relationships continued to evolve. For example, a student member reflected: "*The study abroad trip seemed to change team member's individual opinion on the possibility to make ACTUAL change on [study abroad location]."* In year two, the team split into three sub-teams based on the knowledge and skills members accumulated in year one and on the trip.

4.3 Case Three: Product Redesign Scope with Assigned Roles

Case three contained a team of seven members working on a project classified as a "redesign" project. The aim of the project was to design a wind turbine for a competition sponsored by the

United States Department of Energy. There was a low level of ambiguity in case three, as the technology, problem, and stakeholder were all determined by the very nature of the project. The clear-cut nature of this project allowed this team to use the traditional project management strategies taught in the engineering curriculum. The team assigned roles arbitrarily, as it was clear what needed to be done, but no members came onto the team with any expertise in wind technology. In fact, one student on the team worried from the day project teams were assigned that the team was marked by a general lack of competence or expertise:

> *But, I already had a bad feeling about my team when it came to 'natural ability'…As every team member arrived my chest sunk a little bit. I saw no chance of hope, from the very beginning…Not only did I not trust the ability of my team, but I didn't trust the ability of myself.*

Because this project lent itself well to a traditional project management style, roles and tasks were divided and scheduled quickly. The expectation was that no one on the team was competent from the beginning, but they were to develop competency through fulfilling their assigned roles. Individual team members learned how to fulfill their designated technical roles by the struggling, practicing, and exploring framework described by Tomko's "learning by doing" process. However, the team as an aggregate did a lot of "learning by way of others" as they observed, collaborated with, and were trained by others on how to approach the project. The learning this team experienced in the first semester of the project was largely facilitated by meetings and lectures with their faculty advisor, because *the content is brand new, out of our element, and requires attention and constant clarification.* This team was also able to learn through the mentorship of the senior capstone team working towards competing in the same competition.

4.4 Case Four: Technology Focused Scope and Expert Roles

Case four featured a team comprised of eight members seeking an application for drone technology coupled with multispectral cameras. The project featured a relatively low level of ambiguity, as the team quickly identified a use for the technology. As such, roles were assigned from the beginning, based on the skills members' possessed at the outset of the project. While some members were given flexibility to float between roles and pick up new skills, many members became entrenched and rigid in the fulfillment of their roles. From this, a general hierarchical structure of the team developed, with each member holding expertise in a particular skill set. If others were to develop that skill, the designated "expert" would then need to teach them. Thus, learning in this case was unidirectional from expert to novice learner and privileged "learning through others." Rather than simply learning by doing, if one was going to "do" they first had to be taught by someone else. In other words, learning by way of others seemed to be the only process allowed by the team dynamics. Little time was left for experimentation and organic skills development, as evidenced by this situation:

> *I'm getting another shot, Jay asks me again to try and create a power adapter cable for the drone. This time, he leaves less to chance. He tells me exactly how he wants the design to look. He only asks me to snip and solder all of the parts together.*

Leaving little time for trial and error and learning on one's own by doing, after a student fails at a given task, another team member steps in and explains exactly what needed to be done so that the same mistakes would not be made again. The student describing the encounter above was one of the team members with a floating role, and this student had to be taught by an expert how to do each task required.

In addition to learning through teaching, this team was also learning about design intuition and had moments of self-reflexivity and extrospection also described in Tomko's learning typology [14]. Perhaps because this project began with such a low level of ambiguity, the team struggled in semester two when a faculty advisor suggested the team revise their scope:

> *We're afraid, given the freedom, we will be too vague about our project. This stems from a thinking that we are all in such different views of this project… It seems like we just started the project all over again. We don't completely understand what scope we are following, and that puts us in a scary place for our scope to creep…We also have a building anxiety over our scope, and problem statements which seem to be actively changing.*

When faced with revising their project scope, the team had to rely on and develop their "design intuition" in order to redirect the application of their technology. This temporary ambiguity caused members to evaluate their own perception and their teammates perceptions of the project, being both intro- and extrospective, as they identified the limitations and opportunities associated with their design project.

5 Discussion and Conclusion

The cases described above in this work in progress paper demonstrates the complex parameters that affect the type of roles and learning that can occur on a two-year engineering capstone team. These parameters include varying project scope, strategies and methods used to develop roles, and levels of ambiguity. Within all the parameters, a level of influence on the type of learning that will occur on the capstone team is present. Teams with an entrepreneurial scope and higher amounts of ambiguity (cases one and two) experienced high levels of inter- and intra-personal learning. As members developed their projects from the ground up, they had to learn what their project was and who they were on the team. Roles developed organically on both of the teams characterized by an entrepreneurial scope, as members became more acquainted with the project. In case two, these organic roles became formalized in the second year of the project, as sub-teams were created. However, this division of labor wasn't possible for the members in case one, due in part to the limited team size, but also because the ambiguity remained relatively high

longer than in case two. The project in case one continued to have scope changes into the second year of the project, which required team members to be more nimble in attending to the demand for changed the roles that needed to be filled. With ever changing roles and limited team members, learning was constantly being shared between members.

From this data it appears that with less ambiguity in the project, teams are able to adopt more formal roles and traditional project management styles which result in the occurrence different learning processes and skills. In cases where project scope and team size allowed for sub-teams to be created and more formal roles to be filled (cases two, three and four), knowledge could be sequestered by specific members of the team and was only shared with the others as necessary. Of course, across all groups there were examples of "learning through others," but in case one this was more like "learning alongside of others" as it overlapped as "learning through doing" together. Whereas across the other three cases, learning through others looked more like instructional moments where one team member imparted their content knowledge to an another: "learning by teaching one another." Learning by way of teaching played a particularly important role in cases three and four, since the low levels of ambiguity made identifying experts relatively easy. Even when case four experienced temporary ambiguity in project scope, they had enough foundational knowledge of the project and enough experts to turn to for advice that they were able to develop their design intuition and redirect the project quickly. This temporary ambiguity experienced in case four also incited some of the self-reflexive and extrospective learning that was also displayed in case one as the team's project scope was developed from scratch.

In all cases, members experienced learning by working with their hands and trying new things or *learning by doing*, but even this manifested itself differently across teams. For example, in case four, where the team had expert members teaching novice members new tasks, there was seemingly little room for error and experimentation. When a novice member tried something and failed, an expert intervened and corrected them, explained step by step what needed to be done. In case one on the other hand, experimenting and failing was a necessity and characterized their experiences of learning throughout the project. There were no experts or step by step instructions; the only option was to experiment and try and help the other do the same – as these two processes were often simultaneous. Reflecting on the team's general lack of expertise, one member in case one put it simply: *so we're learning by doing I guess.*

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References

[1] K. Charmaz, Constructing Grounded Theory, Thousand Oaks: Sage, 2014.

[2] B. G. Glaser and A. L. Strauss, The Discovery of Grounded Theory: Strategies for Qualitative Research, New York: Aldine De Gruyter, 1967.

[3] L. L. Putnam and C. Stohl, "Bona fide groups: A reconceptualization of groups in context," Communication Studies, vol. 41, no. 3, pp. 248-265, 1990.

[4] J. R. Wieselmann, E. A. Dare, E. A. Ring-Whalen and G. H. Roehrig, ""I just do what the boys tell me": Exploring small group student interactions in an integrated STEM unit," Journal of Research in Science Teaching, pp. 112-144, 11 July 2019.

[5] M. A. Peeters, C. G. Rutte, H. F. J. M. van Tuijl and I. M. M. J. Reymen, "Designing in Teams; Does Personality Matter?," Small Group Research, vol. 39, no. 4, pp. 438-467, 2008.

[6] M.-É. Roberge, Q. J. Xu and D. M. Rousseau, "Collective Personality Effects on Group Citizenship Behavior: Do Diverse Groups Benefit More?," Small Group Research, vol. 43, no. 4, pp. 410-442, 2012.

[7] L. Van Dyne and J. A. LePine, "Helping and voice extra-role behaviors: Evidence of construct and predictive validity," Academy of Management Journal, vol. 41, no. 1, pp. 108-119, 1998.

[8] J. E. Driskell and E. Salas, "Collective Behavior and Team Performance," The Journal of the Human Factors and Ergonomics Society, vol. 34, no. 3, pp. 277-288, 1992.

[9] J. W. Chang, T. Sy and J. N. Choi, "Team Emotional Intelligence and Performance: Interactive Dynamics between Leaders and Members," Small Group Research, vol. 43, no. 1, pp. 75-104, 2012.

[10] B. Mennecke and J. Bradley, "Making Project Groups Work: The Impact of Structuring Group Roles On the Performance and Perception of Information Systems Project Teams," in International Academy for Information Management, Atlanta, 1997.

[11] J. Lave * E. Wenger (1991). Situated learning: Legitimate peripheral participation. Cambridge: Cambridge University Press.

[12] A. Contu & H. Willmott (2003). Re-embedding situatedness: The Importance of power relations in learning theory. Organization Science, 14(3), 283-296. P. 285.

[13] E. Wenger, 2010. Communities of practice and social learning. In C. Blake (Ed.). Social learning systems and communities of practice (pp. 179-198). London: Springer-Verlag.

[14] E. Wenger (1998). Communities of practice as a shared social system. Systems Thinker, 9(5).

[15] E. Wenger (2010). Conceptual tools for CoPs as social learning systems: Boundaries, identities, trajectories, and participation. In C. Black (Ed.). Social learning systems and communities of practice (pp. 125-143). London: Springer-Verlag.

[16] E. Wenger (2010). Conceptual tools for CoPs as social learning systems: Boundaries, identities, trajectories, and participation. In C. Black (Ed.). Social learning systems and communities of practice (pp. 125-143). London: Springer-Verlag.
[17] Tomko, Megan. 2019. "Developing one's "toolbox of design" through the lived experiences of women students: Academic makerspaces as sites for learning." Doctor of Philosophy, Mechanical Engineering, Georgia Institute of Technology.
[18] H. Chang, F. W. Ngunjiri, K-A. C. Hernandez (2013). Collaborative autoethnography. New York: Routledge.
[19] Emerson, R. M., Fretz, R. I., & Shaw, L. L. (1995). *Writing ethnographic fieldnotes*. Chicago: University of Chicago Press.
[20] Tracy, S.J. (2019). *Qualitative research methods: Collecting evidence, crafting analysis, communicating impact* (2nd ed.). Hoboken, NJ: Wiley-Blackwell.