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Developing Students' Engineering Leadership Identity: Development and Results of a Pilot Effort with First Year Students

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Abstract

In an era of scientific and engineering advancement, we need engineers who have a diversified skillset. More specifically, in order to solve many of the complex problems faced today, industry is calling for engineers who combine their technical expertise with leadership qualities. These qualities can be developed in engineering students' formative years as undergraduates. However, how leadership qualities are developed in engineering students is still not well understood in engineering education community. As part of a larger project, this work reviews the development of a pilot intervention with freshman engineering students aimed at furthering that understanding.

This intervention was informed by a combination of quantitative data analysis, qualitative exploration, and engineering leadership identity theory. Quantitative analysis was based on two national data sets; Qualitative exploration was based on 20 engineering focus groups involving 17 majors from three universities. The goal of this research was to identify an intervention that would impact students in ways that cultivated an engineering leadership identity.

To develop this intervention, characteristics of impactful experiences in the development of engineering leadership identity were explored using the data described previously. A transcendental phenomenological approach was used to explore both the content of the experiences (textural) and the context of those experiences (structural). By focusing on the most impactful experiences, a three-pronged intervention was identified. The data indicate that the development of an engineering leadership identity is largely influenced by a bifurcation between technical and interpersonal (or professional) aspects of the profession. Moreover, the data indicates that well-executed group projects and corresponding support activities are instrumental in engineering student leadership development.

Introduction

Industry has consistently called for professionals with a mix of technical and professional skills. The combination of which is not only necessary to successfully navigate the workplace, but it is also needed to allow teams with diverse skill sets to effectively solve the complex interdisciplinary problems that exist today. While the education system has worked to increase graduation rates of technical professionals-- such as engineers—there are persistent demands from industry to improve professional skill competencies [1], [2]. This NSF-funded project has worked to bridge this gap by developing a data-driven understanding of how undergraduate engineers develop as leaders through the lens of identity constructs [3]. The purpose of the study is to better inform education practices that seek to promote engineering leadership skills in undergraduates through the development of a grounded theory. This work has progressed through three phases, beginning with quantitative analysis of two national data sets, followed by collection and analysis of qualitative data from three large universities, and concluding with the implementation and review of informed classroom interventions. The design of the pilot intervention is the focus of this paper.

Literature Review

With the increased complexity of technological problems and the need for technical experts to provide solutions, there is increased interest in improving engineering leadership education [4]. While a veritable collage of theories exists about how to develop leadership in engineering students, the engineering education field has yet to coalesce around a particular framework [5], [6]. While the relative youth of the engineering leadership field may explain the lack of consensus on any single framework for understanding leadership development [7], the widespread implementation of engineering leadership programs point to the need for a firm understanding of how engineering leadership is developed.

Identity and Development

Because of the ubiquity of education as professional training, the question of human development is a core aspect of professional preparation. While many theories have emerged (and faded) in the modern era (constructivism, action learning, cognitive science, etc.), identity has proven itself a powerful framework for understanding human development. It is especially useful when trying to understand multiple aspects of human experience. For example, situated learning uses identity to explain how people gain knowledge within contextual [8], [9]. For example, the Community of Practice model equates education with forging identity [10], [11]. In their seminal text on identity, Chickering and Reisser [12] suggest that education cultivates one's identity growth by empowering individuation. Their model suggests that Reflective Judgement (an identity-based construct) may explain knowledge growth in a profession [13], [14]. Their model proposes a Relationship vector that may be seen as increasing internal control and influence in one's relationships, which is a powerful influence on one's disposition to engage with others. In short, identity models provide a framework for understanding many aspects of development.

Engineering Identity

With the strong connection between identity and education, the engineering education literature is increasingly exploring how to best understand engineering identity [15], [16]. Identity seems to lead to academic and professional persistence [17] and to a stronger connection with the engineering profession [18], [19], [11], [20], [21]. Recent explorations of identity have suggested a more heterogeneous view of engineering identity, where there are different types of engineers with varying values and behaviors [22]. As the field expands, researchers have created and implemented engineering identity assessment instruments [23], [24]. Of particular relevance to this paper is a three-pronged view of science identity:

1. Recognition by others;
2. Interest in content; and
3. Performance / Competence beliefs (RIPC) [25].

Finally, Morelock [26] conducted a comprehensive literature review on engineering identity that separated the field into four interpretive categories: overlay, perception, engagement, and action. This literature indicates that identity is a rich construct for understanding the ways in which engineers may develop and come to understand their worlds.

Leadership Identity

The path of leadership theory has progressed from the 'great man' theory, through leadership skills and behaviors [27]. However, some research indicates this one-dimensional approach to leadership training my not be effective in achieving useful leadership practices [28], [29], [30]. Hence, more multi-pronged approaches to leadership development have emerged, such as servant leadership, socially responsible leadership, and identity-based models [31], [32], [33], [34]. The Leadership Identity Development (LID) model has been especially influential in understanding leadership development in the college environment [35]. The LID model proposes that students move through six stages of increasing complexity of leadership understanding and practice:

1. Awareness—one realizes that leaders exist;
2. Exploration—one assumes membership and responsibilities in groups;
3. Identification—one believes in the centrality of the leader to group success;
4. Leadership differentiated—one realizes that leader*ship* occurs in all groups;
5. Generativity—one becomes committed to group success and interdependence;
6. Integration—one has integrated leadership into their own identity.

While the LID model does not yet have a validated survey instrument, one national dataset used in the quantitative component of this research includes several measures that closely related to identity constructs, as discussed in Methods and in previous research [36].

Engineering Leadership Identity

Given the importance of engineering education, leadership development, and identity as an explanatory theory, it is not surprising that literature is beginning to explore engineering leadership identity (ELI) [6]. While the field is just budding, research is beginning to identify useful models [37]. For example, qualitative research of engineers in industry found three facets of an engineering identity:

1. Technical Mastery – skill at solving problems;
2. Collaborative Optimization – ability to influence teams; and
3. Organizational Innovation—ability to create novel, market-driven solutions [38].

A quantitative exploration of characteristics of effective engineering leadership development found that curricular experiences may be the most effective approach to achieve it and that programmatic initiatives had little impact on development [4]. Despite this growing body of knowledge, a long road lies ahead before the field reflects a complete, data-driven understanding of engineering leadership development.

The Engineering Leadership Identity Project

Schell and Hughes proposed a multi-staged grounded theory approach [39] to understanding the development of engineering leadership identity [40]. Their project consists of three stages: an initial quantitative stage, a subsequent qualitative stage, and a final grounded theory stage. See their literature for a fuller discussion of the project and methods (e.g. [41], [42], [43]). This current research is focused on interventions informed by the first two stages.

Methods

The strategy used to create interventions had three stages: 1) Thematic coding of experiences, 2) Identification of impactful characteristics, and 3) Development of a relevant intervention. First, previous findings, artifacts of quantitative analysis, and the data itself were reviewed to explore influential experiences in students' ELI development. Transcripts were iteratively coded (openly, then axially) in advancing levels of granularity, focusing on the nature of those experiences central to participant leadership development [44]. Nvivo qualitative software (version 12) was used for analysis. A social constructivist approach was taken regarding knowledge creation. Here, one's understanding of the world is developed within the context of an engineering program.

Second, these totals were compared to determine the relative prominence of comparable ideas. In addition, non-coded ideas that were latent, but also apparent in the data were allowed to emerge; These instead were implicit to how participants talked about ideas and were woven into the fabric of discussions. Attention was also given to differences across groups, defined by factors such as demographics and class year. The most prominent ideas were used to identify impactful characteristics of activities that cultivated EL development. Finally, data were separated according to textural and structural themes.

Third, an intervention was created that reflected as many of these impactful characteristics as possible. This intervention was then piloted in the spring semester of 2020. IRB approval was received for this research. The intervention is intended to be descriptive of the types of activities that impact engineering students in their leadership development. Therefore, this intervention will serve two purposes: 1) It will validate project findings; 2) It will provide a template for a curricular approach to engineering leadership identity development.

Qualitative Data

The qualitative data that formed the foundation of this research was collected in the form of focus groups held at three U.S. universities. The participating universities represent a range of institutional settings in the form diversity of population as well as diversity of student experience. A total of 20 focus groups have been held with 64 students, who represent 17 different engineering majors. This has resulted in over 22 hours of recorded material. The protocol covers sections on engineering, leadership, and engineering leadership identities, and it was developed through compilation, review and refinement of questions from nearly 40 related studies. Focus groups lasted approximately one hour. They were digitally recorded and transcribed verbatim by a third-party transcription service.

Findings

The characteristics of experiences that were impactful in the development of an engineering leadership identity were used to create the intervention. Students responded provided textural descriptions addressing the question, "What happened during development?" These themes clearly fell into Technical and Professional categories, as indicated in Figure 1. The bifurcation of textural codes into technical and professional themes agree with the existing research on engineering identity [20] , or by Technical Masters / Collaborative Optimizers / Organizational Innovators [38]. Additionally, student experiences relayed structural information addressing the question, "What was the context surrounding formative developmental experiences?" These structural themes identified influential good practices, such as group work, scaffolding, and mentor-like behavior. Figure 2 outlines these findings.

Textural, Technical

In the Technical category, summarized in the top half of Figure 1, students felt that confidence in technical expertise was a prerequisite to any engineering leadership engagement. For engineers, this often meant problem-solving skills or expertise in particular content matter. Students who stepped into engineering leadership roles often reported self-efficacy in their ability to navigate the technical challenges due to either previous experience or extensive previous classwork. Moreover, the relative expertise of these students seemed to be recognized by their peers. What was striking however, was the frequency with which participants reported feeling inadequate to step into roles of increased responsibility, when technical skills were essential. Given this common hesitation, it is not surprising that so many engineering students did not view themselves as engineering leaders. It may be that classroom experiences that focus on learning new technical material (rather than applying existing knowledge in creative or interesting contexts) creates an environment of perceived inadequacy. Or, it may be that students simply lack examples of applying technical knowledge, so they have no framework within which they can feel confident. That said, many participants did feel like they were progressing towards a state of competence as an engineering leader.

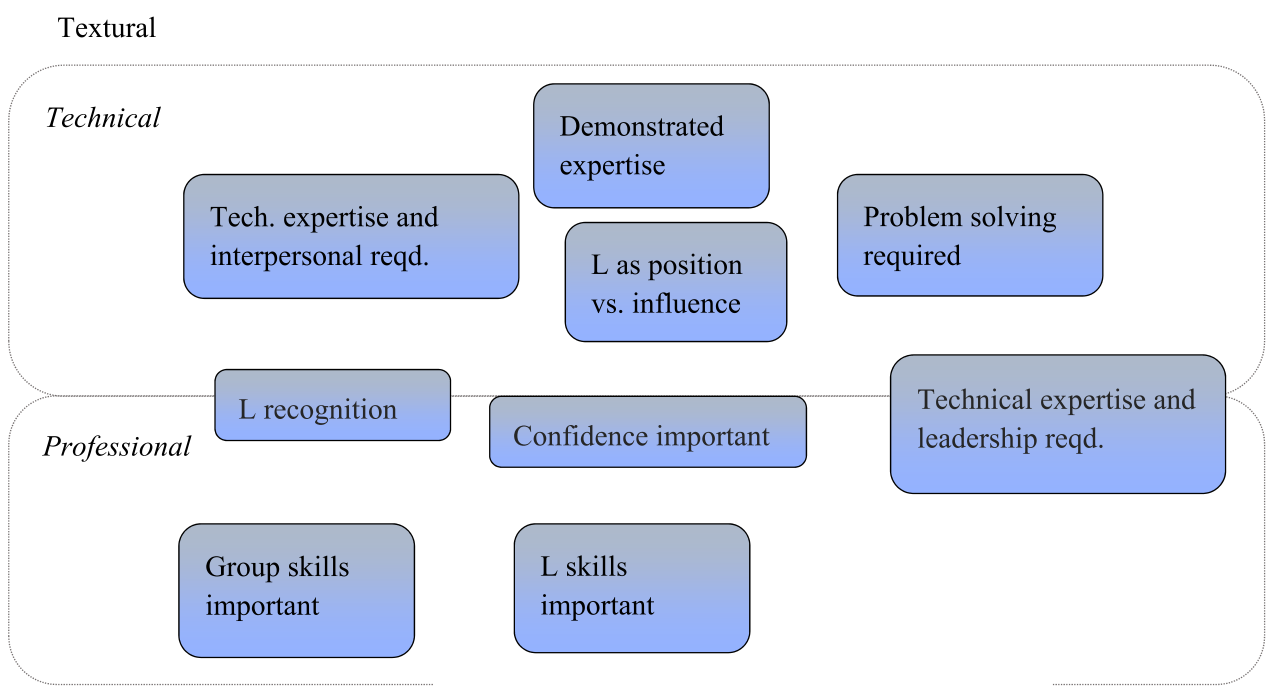

Figure 1, Textural Themes

Another aspect of the technical category was the expansive view with which participants grew to view the engineering profession, in two core ways. First, as they began to perceive the depth of their field and the breadth of engineering overall, they saw the need for both technical expertise and interpersonal relationships in successful projects. In fact, several participants noted that group work where one person was physically unable to do it all demanded development of group skills. Second, participants who engaged with more authentic team-based projects (e.g. internships or group projects for actual companies) felt increasing responsibility for their work; They felt technical expertise and leadership competency were required to successfully lead a project.

Participant focus on technical expertise and problem-solving agrees with typical perceptions of engineering values. Our research has shown that students often believe feeling confident in one's technical understanding is a necessary (but insufficient) criteria for exercising leadership.

This may reflect either the influence of the ubiquitous focus on technical competence in school, or it may reflect personal values engineering students have about practicing their profession. Regardless, technical proficiency (or at least recognition of it) seems to be an entrance criterion into leadership roles.

Textural, Professional

The other influential textural category was professional skills, summarized in the bottom half of Figure 1. In the Professional category, confidence (this time in group skills) was once again a core influence on participant willingness to engage with the group. Participants talked about professional skills (such as delegation, communication, and collaboration) extensively, reflecting the centrality of this idea in leadership development and their own confidence.

A second theme that emerged during the analysis was leadership skills, such as delegation, big picture thinking, and sensitivity to group dynamics. Students experienced in leadership talked about the importance of developing these skills. For example, by recognizing the strengths and weaknesses of various members within a team, leaders felt that they could delegate tasks more appropriately. Of particular note, one student talked about the need for empathy, since it empowered the leader to support team members when they needed help or guidance. This perspective resonates with the servant leadership model [45].

Another key factor in the development of interpersonal skills relates to engineering student progression in technical competence. As engineers progress in their undergraduate career, their technical knowledge grows substantially. Hence, it becomes more practical to use these skills to work in a group setting. Moreover, this growth enables groups to address truly useful and interesting problems by dividing expertise amongst various group members, thereby providing a venue to practice professional skills.

Structural

Participants also spoke at length regarding structural components found commonly in a well-designed and executed curriculum, per Figure 2. Participants often reported that group project experiences were instrumental in their development, especially when working towards a technical solution. It may be that one is seeing that experience-based education and applied learning have an especially deep impact in an engineering content. Or, it may be that engineering students are especially impacted by working together towards a common goal. In addtion, mentorship by others (be they faculty, peers, or others) was essential to students developing a more relational view of engineering leadership. Good leaders gave students examples of ways of acting that they later were able to mimic. Interestingly, bad leaders were also impactful, as they highlighted the importance of effective interpersonal skills. Finally, reflective and applied learning were pedagogical approaches [46], [47], [48] that cultivated growth in engineering leadership. It may be that reflection provides a way to makes sense of experience, which further cements one's place in the world, thereby building identity. It should also be noted that no noteworthy differences were found in terms of participant demographics or other higher-level impacts rooted in the institution characteristics at this level of analysis. In summary, student inclination to assume increasing responsibility was cultivated through authentic activities where they were able to work with others towards a common technical goal.

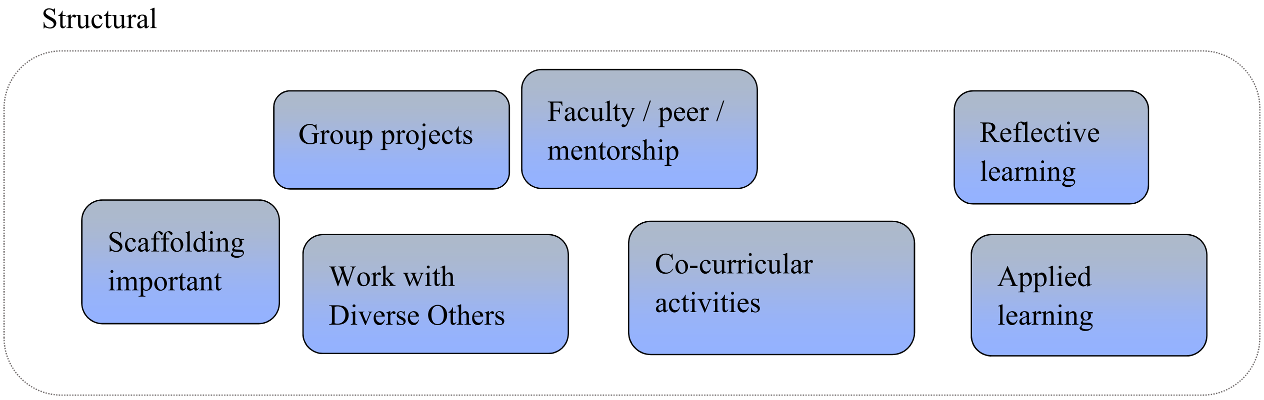

Figure 2, Structural Themes

Intervention

These textural and structural characteristics informed the creation of a 3-pronged intervention, implemented in an introductory classes in Industrial Engineering that was held completely online. The scope and length of the intervention is one week-long activity. The intervention consists of the following three prongs:

1. Pre-lecture video: Students will be assigned several asynchronous pre-lecture videos to watch. Videos will be created to align with group activity requirements. Videos have been shown to better prepare students for activities [49], [50]and to provide accountability [51];
2. Group activity: Students will attempt a jigsaw-structured problem-solving activity that requires all participants' expertise, with measured achievement. This approach ensures that each group member has a particular technical competence that is needed for successful activity completion;
3. Class summary: The class will discuss group findings and accomplishments, and the instructor will reflect on the lessons learned. The focus will be on technical solutions and exploration of relational leadership in the project. By reflecting on the group activity in terms of relational leadership, students can integrate a more relational approach to their interpersonal interactions. Finally, guided class discussion provides an avenue through which technical leadership may be scaffolded and practiced.

Each prong addresses multiple developmental characteristics, so that the student learning environment integrates multiple modes of engagement, as outlined in Figure 3.

In summary, the 3-pronged intervention proposed here includes characteristics of impactful leadership experiences for undergraduate engineering students, grounded in the findings of this study as summarized in Figure 3. Chickering and Gamson's [52] seven principles for good educational practice provided a guide for conducting the course. By creating a data-driven thematic structure of impactful developmental steps, the intervention has a sound foundation.

Discussion

The purpose of this study was to explore the experiences that were most impactful to engineering student leadership development in order to propose an effective class intervention. By identifying the most impactful experiences, and the context within which they occurred, we were able to list characteristics that were essential in affecting student growth. Using these characteristics, a multi-pronged intervention was developed, for use in underclass introductory classes.

The findings of the analysis point to a bifurcated perspective regarding the engineering profession, where technical and professional competencies are valued. Students who have had these two types of experiences are better able to navigate professional communities and expectations, if industry voices are to be believed. Moreover, the evidence suggests that these types of experiences also cultivate growth in engineering leadership identity, which may lead to persistence and higher engagement in the profession. However, this finding also points to the ways in which many current curricular programs fail students, since these types of collaborative experiences are often reserved for upper-class students. Administrators and interested educators may do well to note that the paucity of collaborative projects early in engineering students' education may have a direct impact on the level of professional skills they are able to achieve.

In addition, participant frequent discussion of self-efficacy in both technical and interpersonal fields reflect the high level of competency they expect of themselves. This can be problematic as a barrier to student growth in non-technical areas. Here, again, the Community of Practice model is useful, as it foregrounds communal recognition as the currency through which belonging is conferred.

Finally, this research only involves the most impactful characteristics of engineering leadership development experiences. With continued research and analysis in other venues, more comprehensive understanding of the challenges facing development may be uncovered. With this insight, interventions may be developed in a more strategic, systematic, and comprehensive way to affect change in engineering leadership education. In particular, this research will inform longer-term interventions across a broader array of engineering courses, in terms of content and location in program.

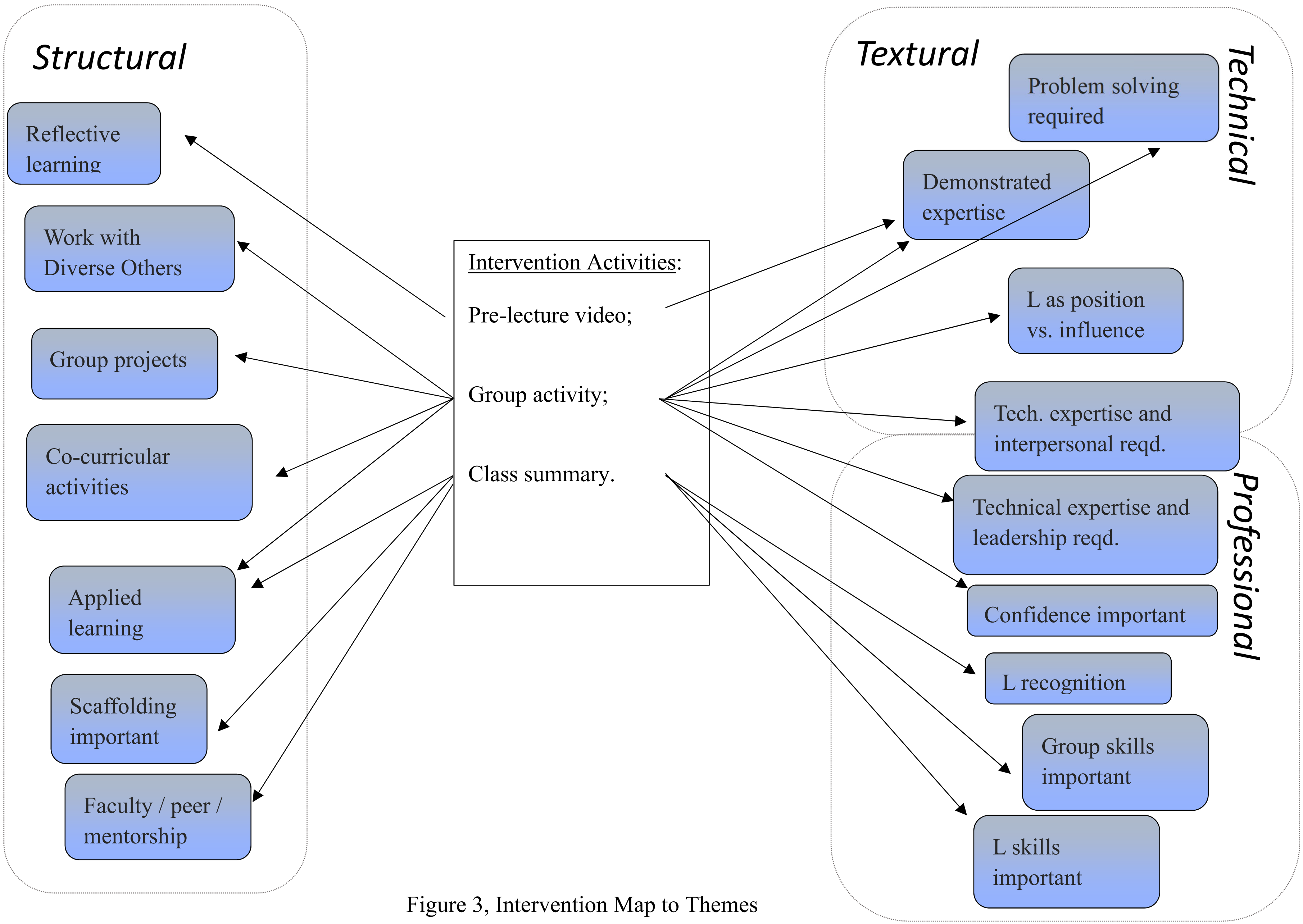

Figure 3, Intervention Map to Themes

Limitations
There are several limitations to this research. First, the intervention will only be tested initially at Montana State University; Readers are cautioned regarding transferability of results in dissimilar conditions. Second, the intervention will cover only one week's worth of class in one course, which was held online due to COVID-19 response measures. This time restriction limits the ability of the intervention to fully impact ELI development, which may result in weak student development outcomes. Third, this research only reflects initial data analysis. Further work may uncover additional characteristics of engineering leadership growth that could prove vital to affecting development. That said, the characteristics described here are central to identity formation, so more integrated interventions are expected to improve the complexity and effectiveness of operationalization, but not change its focus or tone. Fourth, this intervention only lasted one week. Research has indicated that changes to identity occur over a much longer time period, so longer-term interventions may prove more impactful.

Conclusion
Engineering leadership identity is a potent framework for exploring student development. Moreover, it may very well hold the key to developing an engineering curriculum that meets industry demands, as well as ABET leadership requirement. And, by crafting a more communal training experience for future engineers, students may come to value the complex richness of the engineering profession, and even come to enjoy working with others. By preparing students through collaborative spaces that demand technical competence, including them in authentic environments, and scaffolding and practicing relational leadership behaviors, their professional training in university can be more meaningful and valuable to the students, their future industrial partners, and society. This research involved a rich exploration of those experiences that formed how engineering students positioned themselves in the world. The authors look forward to a time when institutions strategically cultivate impactful experiences, rather than leaving them to chance.

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