The Formation of Undergraduate Engineers as Engineering Leaders

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Abstract
Today, leaders of industry and government are calling for increasing numbers of engineering graduates to maintain the nation’s economic competitiveness. However, the expected positive impact from increasing the number of engineering graduates will be limited, unless the full capabilities of these graduates are harnessed. Specifically, solving today’s complex challenges will require cooperation among experts from many fields. In order for these collaborations to be successful, leaders of these groups must harness the diverse capabilities of their members. This will require skilled technical leaders, many of whom should be engineers. Therefore, undergraduate engineering students need to learn how to be effective leaders during their formation as engineers. Unfortunately, many engineers graduate with little development of leadership skills and engineering educators do not currently have sufficient understanding of how engineering students develop into leaders.

This NSF ECE supported project seeks to close that gap by improving our understanding of the role leadership plays in the process of becoming an engineer. Specifically, this work investigates the role of leadership as a component of the development of an engineering identity in undergraduate students. By building on the idea that seeing oneself as an engineering leader requires the development of an engineering identity in combination with the development of a leadership identity, this work investigates the process of becoming an engineering leader and leverages the central role identity plays in learning. The investigation began by analyzing a national data set of students’ leadership development experiences and the self-reported impact of those experiences. The data was used to explore the leadership experience and perception of the impact of these experiences of engineering students when compared to their peers in other STEM fields and those outside the STEM fields. Initial results indicate significant differences between these groups.

Introduction
As society finds itself facing ever more complex challenges, many have rightfully called for training greater numbers of engineers to provide our workforce with the skills needed to successfully design solutions to these challenges [1]. However, designing these solutions is difficult not simply due to the complexity of the problems, but also because of the very nature of the engineering design process. In a seminal work in the area, Bucciarelli [2] revealed that design is a social process that only exists in a collective sense. In order to lead this social process and ensure that the capabilities of an expanded engineering workforce are successfully harnessed, new engineers must be more than just technical experts, they must also be technical leaders [3, 4]. This need is the impetus for developing greater levels of engineering leadership in undergraduate students.

While the Green Report called for inclusion of leadership in engineering education over a generation ago [5], the engineering education community has only recently built momentum in this area, shown by increasing research activity and, in 2014, developing a leadership focused division of the American Society for Engineering Education [6]. Perhaps the most visible aspect of this momentum is the establishment of engineering leadership certificates and minors through centers at universities throughout the country [7, 8]. While the implementation of these programs
is a step forward, most programs tend to focus on leadership as a set of skills or experiences bolted onto a traditional engineering education [9]. This approach does little to understand the more complete picture of how leadership fits into the broader view of the heterogeneous nature of engineering work [10], and the role leadership plays in the formation of an engineering identity.

The work presented here addresses this gap through a sequential, mixed-methods study. The overall goal of this study is to construct a grounded theory of engineering leadership as a component of the professional formation of undergraduate engineers. Informed by an analysis of national data, the grounded theory approach will lead to an explanatory model of engineering leadership identity development. An initial application of the model will develop and test a series of educational interventions, enabling engineering educators to more effectively train engineering students in leadership. In the first phase, existing national data sets of college students are analyzed using quantitative methods to better understand how engineering students view and experience leadership and how these views and experiences compare with their peers in other areas of study. Through this phase the project will answer the following specific research questions:

1. How does leadership identity in engineering students compare to those in other fields?
   - H1. Engineering undergraduates are less likely to pursue formal leadership opportunities than their peers in other STEM and non-STEM fields.
   - H2. Engineering undergraduates’ leadership experiences are of lower quality than their peers.
   - H3. Engineering undergraduates have lower leadership self-concept than their peers.

2. What is the relationship between leadership identity and engineering identity?
   - H4. Engineering undergraduates’ leadership self-concept negatively correlates with engineering identity
   - H5. Experiences that contribute to engineering identity will negatively impact leadership self-concept for engineering undergraduates.

The quantitative analysis will provide a key foundation for a second phase of the project deploying qualitative methods. This qualitative study will utilize grounded theory to explore engineering students’ experiences to answer the following research question:

3. How do engineering undergraduates define engineering leadership and develop a sense of engineering leadership identity?

The project is currently completing the quantitative phase and preparing the protocols to be deployed in the qualitative phase.

**Methods and Data**

In this work we will examine the quantitative phase of the project including the data sets and methods of analysis employed.

**Quantitative Data Sources and Sample**

Previous research indicates that engineers tend to lack interest in or even hold a disdain for leadership [11] and other non-technical aspects of engineering [10]. In addition, little existing research has examined engineering students’ leadership experiences nationally. The quantitative phase of the project uses data from two existing national studies of college students to compare engineering students’ experiences with leadership to those of their peers. The data for this phase
of the project will be collected from the National Survey of Student Engagement (NSSE) at Indiana University and the Higher Education Research Institute (HERI) at UCLA, both of whom administer national surveys of college students on an annual basis.

The first source of data is a cross-sectional dataset from NSSE using variables from a pilot module tested in 2015 as part of their larger national survey. The pilot module was designed to explore the quality of students’ leadership experiences. The NSSE survey is one of the largest national surveys of college students—over 320,000 students at more than 560 institutions participated in 2015—and examines students’ perceptions of the contributions of institutional practices to their engagement in college [12]. The pilot module includes items that examine the types of leadership experiences students have, the skills developed as a result of leadership experiences, and the activities performed and feedback received during leadership experiences. The project is the first use of data from the pilot module. NSSE data is used to compare the types and quality of leadership experiences of engineering students to their peers in other STEM disciplines as well as students in non-STEM majors.

The second dataset is a longitudinal dataset from HERI taken from their Freshman Survey (TFS) and College Senior Survey (CSS). The TFS is the longest running national survey of incoming college students, consisting of hundreds of thousands of students from hundreds of colleges and universities across the nation [13]. The CSS is a follow-up survey administered by HERI to students at the end of their fourth year. Student responses on the CSS are linked to their initial responses on the TFS to provide a longitudinal dataset for analysis of the effects various college experiences have on academic and social outcomes. These datasets include a set of items measuring leadership self-concept, a proxy for measuring leadership identity. These questions are asked at both survey time points to allow for analysis of change in leadership from college entry through graduation. These datasets also include items that have been used to measure both STEM identity and engineering identity in previous research [14, 15]. This dataset will be used to assess the relationship between engineering identity and leadership development.

**Quantitative Data Analysis**

Standard best practices for analysis of quantitative survey data have been applied throughout [16-18]. First, all items were examined for assumption violations to determine whether variable transformations were warranted before analysis. Second, all variables are assessed for missing values to determine the appropriate method for handling missing data. Missing data was addressed using listwise deletion or multiple imputation. Listwise deletion is the most robust method for handling missing data, but multiple imputation, a method that is recommended when data are missing at random, is used when listwise deletion may greatly reduce the power of a dataset by removing a large number of cases that may be missing information from only a very few variables [19]. To date, all missing data has been handled through listwise deletion.

The NSSE dataset was used to address components of both Research Questions 1 and 2. This dataset was analyzed using descriptive, bivariate, and multivariate statistics to test these group comparisons. Items from this dataset that have been tested include:

- Whether students held a formal leadership role in an organization
- Setting for leadership role (e.g., student organization, academic setting, minority student group)
• Average number of hours per week spent on leadership activities
• Frequency student received feedback from advisor on performance in leadership role
• Extent to which leadership role contributed to skills in speaking, critical thinking, problem-solving, interacting with diverse groups, and becoming a leader

The HERI dataset is being used to address Research Question 2, and analysis on this dataset is currently at a preliminary stage. Using leadership self-efficacy and social self-concept as proxies for leadership identity, the longitudinal dataset will be analyzed using multi-level regression techniques to isolate the specific effect of engineering identity, and activities intended to enhance engineering identity, on leadership identity. Engineering identity will be derived from exploratory and confirmatory factor analyses on three specific items measured on both TFS and CSS instruments assessing students’ perceived personal importance of: 1) making a theoretical contribution to science, 2) being recognized by one’s colleagues for contributions to one’s field, and 3) becoming an authority in one’s field.

Initial Findings from Quantitative Project Phase
To date, the two quantitative data sets have been utilized to investigate portions of Research Question 1 (RQ1) and Research Question 2 (RQ2). This work began with a direct investigation of RQ1 using the NSSE data. This investigation found that, among college seniors, engineering students were most likely to report having held a leadership role in a student organization (39.7%), followed by students in other STEM fields (38.1%) and then non-STEM students (29.4%). This difference was significant ($\chi^2(2) = 18.928, p < 0.001$). Engineering students who held formal leadership roles were most likely to characterize these as president or chairperson (26%), other executive role like secretary or treasurer (16%), and manager or coordinator (12%). Among those engineering students who held a formal position but did not consider themselves as having held a leadership role, the position held tended to be manager or coordinator (25%), instructor or teaching assistant (21%), or tutor (17%). For greater discussion of these findings, see our earlier work [20]. These findings have recently been confirmed with initial analysis of the HERI dataset.

In the first step in our investigation of RQ 2, the NSSE data set was utilized to explore the differences between majors in how they perceive the benefit of being engaged in leadership roles vs. a variety of leadership related outcomes. Figure 1 displays the results of the cross-tabulation comparing student perceptions of how their leadership role contributed to the development of these outcomes. The bars in Figure 1 display the proportion within each student group who indicated either “quite a bit” or “very much” in response to the item. The asterisks indicate the level of significance of each difference. All comparisons were significant at a level of $\alpha = 0.05$ or lower. Perhaps the most striking aspect of these charts is the consistent pattern across all dimensions that shows engineering students perceive their leadership roles contributing the least to each outcome, followed by students in other STEM fields, with non-STEM students attributing the highest perceived gains from their leadership role(s).

Students across the board felt their leadership role provided the greatest benefit in their ability to work effectively with others, with only a slight difference between non-STEM and other STEM students (1.7%) and a much larger difference between non-STEM and engineering students (13.3%). Students felt their leadership roles contributed to understanding concepts in their majors the least, ranging from less than one-third among engineering students to slightly more than half
of non-STEM students. One of the starkest differences was with regard to becoming a leader outside of college. While more than three-quarters (79.1%) of non-STEM students and slightly less than three-quarters (73.3%) of other STEM students felt their leadership roles contributed to this outcome, only 57.6% of engineering students felt the same way.

Current project efforts are developing regression models for each of the eight leadership outcomes included in Figure 1. These efforts are beginning to examine the differences in the efficacy of various development activities for each group of majors; engineers, other STEM, and non-STEM. Overall, several college experiences, including those associated with a leadership role, significantly predicted engineering students’ perceptions of their gains in the eight leadership outcomes measured here. The experiences that made the most substantial positive impact on these outcomes include the inclusion of leadership experiences in coursework or course discussion and interacting with people from a background different than your own. Both of these predictors had a significant positive impact on four of the outcomes measured and did not negatively impact a single outcome in a significant way. A complete discussion of the results of this analysis are published in a different paper at this conference, see [21] for these details.

**Implications and Future Work**

To date, initial results appear to provide support for the hypothesized negative effect that an engineering identity has on a leadership identity, as illustrated by the red line in Figure 2.
As depicted in Figure 3, as the project enters its ninth month, the team is finalizing a series of publications that complete the exploration of the NSSE dataset and beginning exploration of the HERI data set. As the quantitative phase of the work closes over the next several months, the team is also beginning to develop the protocols needed for the qualitative phase of the work and development of the grounded theory. Initial results of this work are available in the poster shared at the 2018 ASEE Conference and Exposition.

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References


