Understanding Undergraduate Engineering Researchers and How They Learn

Lisa C. Benson, Marian S. Kennedy, Katherine M. Ehlert
Department of Engineering and Science Education
Clemson University
Clemson, South Carolina, USA

Penelope M. D. Vargas
Department of Education and Human Development
Clemson University
Clemson, South Carolina, USA

Courtney J. Faber
Department of Technological Studies
The College of New Jersey
Ewing, New Jersey, USA

Rachel L. Kajfez, Anne M. McAlister
Department of Engineering Education
The Ohio State University
Columbus, Ohio, USA

***Abstract*—As the need for qualified science, technology, engineering, and mathematics (STEM) graduates increases, there is an accompanying need for improved undergraduate STEM education. Undergraduate Research Experiences (UREs) have been shown to enhance an undergraduate student's academic experience; however, not all students can participate in or have access to UREs due to schedule constraints during the school year or other commitments in the summer. Our current research project seeks to determine how students develop a researcher identity and transform their epistemic beliefs through UREs. Elements identified to contribute to students' researcher identities and epistemic beliefs will then be translated into strategies that can be incorporated into traditional learning environments. This paper will overview the progress made in the first part of this multi-phase, multi-institution project and preliminary results from the initial surveys.**

Keywords—undergraduate research experiences, epistemic beliefs, student perspectives, researcher identity

I. Introduction

With the need to increase creative and collaborative graduates in STEM, administrators and employers have called for improvements in undergraduate STEM education [1]–[4]. One such way to meet this need is through the implementation and expansion of Undergraduate Research Experiences (UREs) [3]. UREs have been shown to improve and elevate the undergraduate experience [5], deepen a student's understanding of their field [6], [7], and lead to increased retention in STEM programs [8], [9]. Although an URE may be a formative experience, some students are unable to participate due to their limited availability or conflicts with summer employment and/or family needs. The ultimate goal of this research is to develop methods that incorporate the benefits of UREs into more traditional learning environments, such as classrooms and laboratories, so that they may be accessible to all students. Previous research on UREs has typically focused on competitive summer research programs and has addressed systematic benefits such as enhanced research skills [10], [11], clarification of career goals, and increased understanding of research processes [12]–[14].

Our research project, "Student Perspectives on Researcher Identity and Transformation of Epistemologies (SPRITE)," seeks to determine how students develop researcher identities and transform their epistemic beliefs through UREs. Our work will focus on identifying the aspects of UREs that affect or inform student identities and epistemic beliefs so that they can be translated into instructional strategies for more traditional learning environments. Specifically, our research questions are:

1) How do undergraduate engineering students conceptualize and construct what it means to be a researcher?

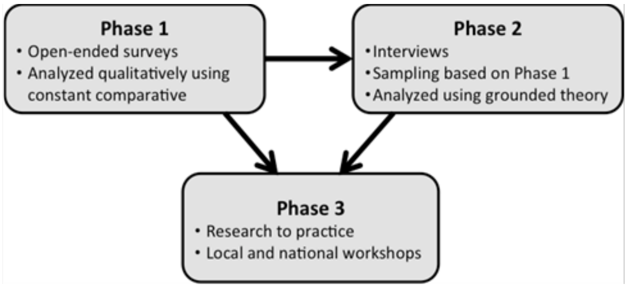
2) What do undergraduate engineering students perceive to be the factors that affect their researcher identity development?

3) How do undergraduate engineering students understand the underlying epistemic frameworks of their fields?

4) How do undergraduate engineering students' perceptions of their own epistemic beliefs develop within the context of their research experiences?

At each institution, students completed a survey with open and closed-ended items (Phase I); based on the survey results, students will be selected for follow-up interviews (Phase II). The results from both the surveys and the interviews will be used to understand how students develop their identity as researchers and how this affects their epistemic beliefs (Phase II). We will then work with educators to develop instructional strategies to help build these benefits into the undergraduate educational experience (Phase III) (Fig. 1).

Fig. 1 Graphic representation of study phases.



II. Theoretical Framework

We will utilize situated learning, epistemic cognition, and identity as our analytic lenses to understand how undergraduates conceptualize research, integrate into a research community, and develop researcher identities. The theory of situated learning, developed by Lave and Wenger, centers on the relationships between learning, identity, and membership in communities of practice [15]. These communities shape an individual's perceptions, values, and interactions with others as members of the community engage in collective learning about a common domain with shared resources [15]. According to situated learning theory, students learn best by doing what experts in that field are doing (authentic tasks), and their gained knowledge is socially, culturally, and physically situated [15], [16]. UREs will serve as the communities of practice in our study, as we first focus on examining students' situated learning in this setting.

Epistemic beliefs can be defined as students' beliefs and attitudes about the nature of knowledge and knowing. In this study, we will apply Chinn et al.'s conceptualization of epistemic cognition to more deeply understand students' epistemic development within a research community of practice [17]. Epistemic cognition is conceptualized as a network of interconnected cognitions that cluster into five separate constructs: 1) epistemic aims and epistemic value, 2) structure of epistemic achievements, 3) source and justification of knowledge and epistemic stances, 4) epistemic virtues and vices (motivations), and 5) processes for achieving epistemic aims. Epistemic aims, such as knowledge, understanding, and true beliefs, are defined as a subset of goals that people adopt related to their desire to figure things out. These goals become epistemic achievements once they have been reached and have different epistemic values based on their worth to an individual. An individual may choose to believe knowledge claims to different extents, taking various epistemic stances. An individual's perceptions about the processes that produce valuable and reliable data can also be investigated to help explain the learning processes of individuals as they engage in inquiry and evaluation task [18].

We will also explore the construct of identity, in which situated learning and epistemic beliefs serve as the foundation of understanding and the community of practice serves as the context. Identities can be understood "as long-term, living relations between persons and their place and participation in communities of practice"[15 p. 35]. Additionally, newcomers in a community of practice develop their identities through legitimate peripheral participation, where they take on active roles in the community [15]. Our study seeks to understand the identities students develop through UREs from the student perspective.

Table 1: Institutional Information[a] and Population of Interest Estimates[b]

Institution	Carnegie Classification™ of Institutions of Higher Education	Setting/ Profile	Acceptance Rate	Undergraduate Enrollment	Enrolled BME Students	Enrolled ME Students	Total Population
Institution 1	RU/VH	suburban, higher transfer-in	52.8%	17,000	329	761	1090
Institution 2	RU/VH	urban, higher transfer-in	53.0%	45,000	557	1308	1865
Institution 3	RU/VH	urban, higher transfer-in	47.6%	41,000	468	849	1317
Institution 4	Master's L	city, lower transfer-in	49.0%	7,000	137	NR	137
Institution 5	RU/H	urban, higher transfer-in	83.9%	17,000	NR	739	739
Total	-	-	-	-	1491	3657	5148

[a] Data were collected form the U.S. News and World Reports, institution webpages, and the Carnegie Classification™ of Institutions of Higher Education.
[b] Most recent enrollment data are reported; however, data may not necessarily be from the same term across institutions. NR = Not reported.

III. Experimental Methods for Phase One

A. Institutions and Data Collection

In Phase I, a survey including open and closed ended questions was distributed to undergraduate engineering students majoring in Mechanical Engineering (ME) and Biomedical Engineering (BME) at five institutions. Data were collected from undergraduate students with research experience at institutions of varying size and type (Table 1).

B. Survey Instrument

The 16 open-ended items on the survey were designed to understand students' conceptualizations of research and their beliefs about themselves as researchers. These items were developed in a prior study that sought to begin to characterize engineering students' researcher identities [19]–[21]. Future work will include a qualitative analysis of students' responses to inform participant selection and question development for follow-up interviews.

The 45 closed-ended items include 30 items designed to measure students' engineering epistemic beliefs and 15 items to measure students' need for cognitive closure. The 30 engineering epistemic belief items were informed by a prior study that sought to understand students' epistemic beliefs and gather evidence for content validity [19]–[21]. This prior study utilized items from Yu and Strobel's Engineering Related Beliefs Questionnaire to measure students' beliefs about the certainty, simplicity, and source of engineering knowledge [22], [23]. Based on students' explanation of their responses that was captured in textboxes below the items and follow-up interviews, the items were modified to remove ambiguities and try to capture the full range of students' beliefs. Additional items were added to capture students' beliefs about the justification of engineering knowledge. These items were modified from Greene et al.'s and Ferguson & Braten's work to be specific to engineering rather than history, math, and natural science [24]–[26].

The 15 need for cognitive closure items were selected from Kruglanski's Need for Cognitive Closure Scale from the discomfort with ambiguity and close-mindedness subscales [26]. These subscales were selected because of their hypothesized influence on epistemic cognition, a focus of this study [17].

C. Phase I Participants

The survey was distributed to undergraduate coordinators (or other representatives) in the BME and ME departments at each institution as established in approved IRB protocols. Initially, survey participants' names were entered into a drawing for an incentive in the form of an electronic gift card. Due to a limited response rate across all institutions during the initial recruiting, the incentive language was adjusted to provide incentives to the first 40 students who completed the survey at each institution and the invitation to complete the survey was re-distributed.

A total of 113 students completed the survey corresponding to a 2.2% response rate of the entire population of BME and ME students across the institutions (Table 1). Although the response rate is very small, we believe that our initial population is an overestimate as not every undergraduate student has had research experience and not every experience is considered research to the undergraduate.

59.3% of the students were male, 40.7% female. Racial distribution was 68.1% Caucasian, 1.8% Black/African American, 12.4% South Asian, 11.5% East Asian, 2.7% Other Asian, 1.8% American Indian/Alaskan Native, and 11.5% identified as 'other'. A majority of respondents were from either the two institutions with the largest total number of enrolled engineers (15.0% Institution 1, 50.4% Institution 2). Respondents were spread across grade levels with 4.4% in their first year, 20.4% in their second year, 23.0% in their third year, 38.9% in their fourth year, 9.7% in their fifth year, and 3.5% in their sixth year.

IV. Quantitative Results

Data presented here were collected as of April 15th, 2016. 45 closed-ended questions using an anchored scale ranging from 1 (Strongly Disagree) to 7 (Strongly Agree). The closed-ended items focused on determining the students' epistemic beliefs and need for cognitive closure in a general setting and in the context of engineering. The data presented here is limited to frequency of student responses to some of the prompts provided on the survey. Although no statistical analysis is currently presented, we believe that these trends presented provide some insight to the views of the cohort.

Students consider engineering problems in the classroom to be different than engineering problems in the real world. Although there are mixed opinions on whether a single answer exists for course problems, most engineering students believe there is not a single answer for real-world problems (Fig. 2). Students also appear slightly more trusting of their engineering professors than practicing engineers (Fig. 3).

Fig. 2. Student frequency response to the statements "Classroom engineering problems have only one right numerical answer." (Classroom) and "Engineering problems outside the classroom have only one right answer." (Real World)

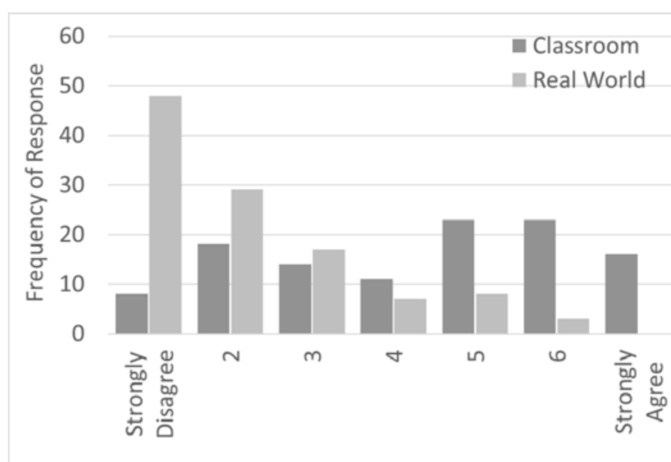
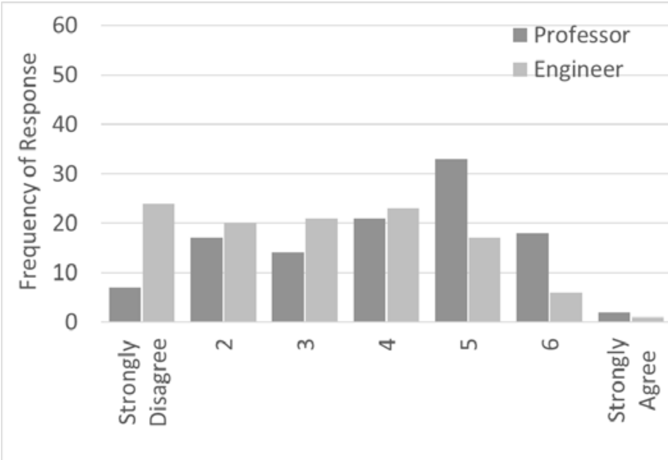


Fig. 3. Student frequency response to the statements "If an engineering teacher says something is a fact, I believe it." (Professor) and "If an engineer says something is a fact, I believe it." (Engineer)



V. Limitations and Future Work

One significant limitation is the narrow analysis of the data presented. We are aware that without statistical analysis, we can only postulate differences that are observed. We are continuing our quantitative analysis with statistical tests. In addition, to help aid in participant selection for Phase II, a cluster analysis will be performed on the quantitative data. Through this cluster analysis, a variety of student perspectives will be captured and analyzed. This will help ensure observations are representative of as many students as possible. Another limitation is that we are unable to validate our quantitative survey items due to the low number of responses received. We are currently considering ways to increase the number of responses to the quantitative items in order to validate them.

As this is a summary of continuing work, data and analysis remain ongoing. Statistical analysis of the quantitative data is not complete. Analysis of the qualitative data (open-ended questions and Phase II interviews) will be presented as it becomes available in future publications.

The collection of the results from Phase I (qualitative analysis, cluster analysis, demographics, etc.) will be used to aid participant selection and interview protocol development for Phase II. Phase II will include semi-structured interviews with undergraduate engineering students. Interviews will be analyzed taking a grounded theory approach to inform the development of a theory and answer our four research questions. Phase III of the project will translate research findings from Phases I and II to engineering education practice through a series of local and national workshops during which the research team, faculty from participating institutions, and other invited educators will identify ways to incorporate and apply effective practices in UREs into more traditional learning environments (classrooms, laboratories, and co-curricular activities).

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