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Enculturating First-Year Engineering Students: A Theoretical Framework*

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The curriculum challenges presented to first-year engineering instructors at a Southwestern institution in the United States as well as the need to highlight the process of theory-building in engineering education motivated a team to conduct an umbrella research project related to the enculturation of engineering students. This umbrella project has generated six conference papers and this manuscript constitutes the last of the series focusing on the changes that students experience and perceive over time, once exposed to the first-year engineering curriculum, and how these changes inform a theory of enculturation. The research questions investigated how students perceive their enculturation, once they have progressed in their engineering programs, and how the results constitute a theory of enculturation. Eight sophomore and junior level engineering students of diverse backgrounds participated in semi-structured interviews and focus groups. Their perceptions were analyzed via quantitative and qualitative strategies of inquiry (i.e. content analysis and open coding) and the resulting themes and associated frequencies were examined to constitute a theory. Informed by prior enculturation studies, this research identified eight dimensions and five themes, thirteen units in total. These thirteen units were organized in extrinsic and intrinsic factors that characterize a theory of enculturation to engineering during the first-year experience and hypothesized on how these units operate to produce professional engineers. This theory of enculturation emphasizes the role of the support systems of schools of engineering which in turn provides a framework that instructors and administrators can utilize when planning or modifying these support systems.

Keywords: enculturation; engineering profession; first-year engineering; professional engineer; theory building

1. Introduction

> PI: "A very well-established emeritus engineering educator, was the first person I ever heard describe the formal undergraduate education of engineering student as 'indoctrination.' I knew he was joking but also serious. As an immigrant myself, fascinated with the idea of cultural assimilation, I had noticed engineering cultural assimilation and gave that meaning to the indoctrination he mentioned."

The undergraduate professional formation of engineers is a topic of global interest. From attraction, to recruitment, and from persistence to graduation rates, numerous initiatives have seen light at the national and global scales to meet the never-ending demand for engineers. Multiple initiatives, institutions, and agencies have assigned resources to investigate and promote the indoctrination the emeritus professor described [1]. Topics that have been heavily scrutinized and researched include the subject of this paper, first-year engineering programs, which in the United States largely reflect a common core model and is the focus of a division of The American Society for Engineering Education (ASEE) as well as a dedicated annual ASEE conference in which instructors share innovative approaches, interventions, and lessons learned [2].

1.1 Motivation and Purpose

The day-to-day challenges faced by a team of first-year engineering instructors at a Southwestern institution, where multiple changes in curriculum occurred during a short period of time, motivated the approach to the first-year experience from a viewpoint of culture acquisition or assimilation-enculturation. On the other hand, the motivation for showcasing the process of theory-building via this case of enculturation stems from the need of our community to make evident and explicit the advancement of knowledge occurring with the research we do in the formation of engineers. Thus, the purpose of this manuscript is twofold: (1) to unveil the enculturation to engineering through the first-year experience at one institution and (2) to demonstrate the process of theory-building in engineering education through the enculturation case.

1.2 Research Questions

This research is framed by the general working definition of culture as the set of values, conventions, or social practices associated with a particular field, activity, or societal characteristic [3]. Enculturation is the process by which an individual learns the traditional content of a culture and assimilates its practices and values [4].

The investigation is part of an NSF-funded umbrella project that originally posed three research questions. Constituting 30% of the research reported in this paper, six conference papers [5–10] have addressed the first two questions

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(RQ1: How do foundational engineering courses facilitate enculturation of first-year engineering students in terms of their performance in engineering enculturation outcome factors? and RQ2: among the engineering enculturation outcome factors, which are perceived by students to be the easiest and/or the most challenging/difficult to achieve?). This paper will address the third question and a new fourth one:

RQ3-How do students' perceptions of enculturation to engineering change over time? The answer to this question will be based on research with students in their sophomore and junior years as they reflect on their enculturation through their first-year engineering experience.

RQ4-How do the findings reveal a theory of enculturation? The answer to this question will exhibit the theory-building process for engineering education.

The contributions of this paper are multiple. First, it highlights the building theory process for engineering education, a process that has inherently been invisible in the field. Second, in so doing, the investigation presents the case of engineering enculturation, describing in detail how a process of enculturation occurs during and after the first-year engineering experience. And finally, by unveiling both the enculturation process and the building theory process, this manuscript informs the academic community, and administrators at different levels, about the opportunities and challenges in the professional formation of engineers via formal and informal interventions.

2. Antecedents and Theoretical Perspectives

2.1 Enculturation to Engineering

This manuscript approaches enculturation from a perspective of professional formation, in other words, as a process of assimilating to professional cultures. In 2008, Boutin-Foster et al. explored the customs, languages, and beliefs systems shared by physicians that comprise the medical professional culture [11]. They described the white coat, the doctor talk, and the physician's explanatory model (not always attuned with the patient's explanatory model) as representative indicators of such culture. They also affirm that medical school educators do not formally discuss the culture of medicine and that it is most often learned through hidden curriculum and role-modeling. Of particular relevance here, they assert that "applying the professional culture of medicine as a framework for teaching about culture can highlight elements within the culture of medicine that are more obvious and tangible to medical students who are in the early stages of their education" [11, p. 108]. Other research describes the enculturation of nurse professionals [12–14] and undergraduate and graduate students studying varied specialties, with emphasis in the minority and international student experience [15–19].

In engineering education, Elizabeth Godfrey has explored the engineering culture over multiple publications. At first, she approached the topic from the assimilation process itself emphasizing students' compliant assimilation [20]. She later delved more deeply into the first-year engineering experience as an opportunity to begin the enculturation process and engineering identity development while recognizing that even at that early stage students could obtain "some appreciation and ability to recognize an 'engineering way of thinking' and 'way of doing' and what it meant to be an engineer" [21, p. 18]. Her later works in the topic characterize the enculturation process adapting Schein's theoretical model of enculturation, with a multi-level process of practices, cultural norms and beliefs [21, 22]. Her last work describes six cultural dimensions of engineering education involving the engineer's way of thinking and way of doing. Yet, this paper does not address the first-year experience directly or the specific curricular domains of the profession – its knowledge, practices, or values [23]. Departing from Godfrey's terminology choices, this paper uses the term enculturation instead of acculturation because of the sociological and psychological views in which the term acculturation has been utilized. Acculturation usually refers to migrants and implies a negotiation between the culture of origin and the receptive or mainstream culture [24–26]. Since engineering students are apprentices, not engineers, the term acculturation seemed inappropriate here.

Other publications on enculturation to engineering use Lave and Wegner's perspective of situated learning and communities of practice [27–31]. Like Godfrey's work, this research does not present a clear and integrated cultural framework, with outcomes or competencies upon which instructional design interventions could be developed. Such a framework is also absent from Cech's study of culture disengagement among engineers and Carberry and Baker's chapter on the impact of culture on engineering and engineering education. Both works identify cultural aspects of engineering education that might negatively impact the exercise of the engineering profession [32, 33]. It is worth noting that as in any culture, cultural norms and master narratives (like masculine culture) are established, yet this manuscript is not a critical view of the way the engineering culture has been instituted. Power structures and relations have shaped the profession, and they are worthy objects of study.

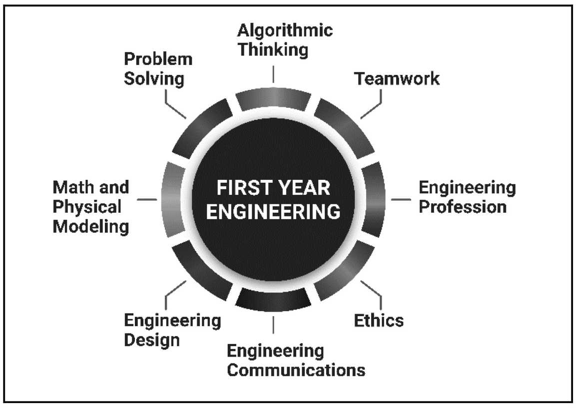

Fig. 1. First-Year Engineering Curricular Dimensions.

Indeed, by exploring the practices, values, and base knowledge that constitutes and separates engineers from other communities of practice, such as physicians, accountants, or lawyers, this paper may be enabling such study in the future. In addition, the perspective of enculturation to engineering of this manuscript does not completely adhere to the engineering identity development school of thought [34, 35]. The internal (intrinsic) process that the student undergoes while becoming an engineer cannot be separated from the procured support system that institutions provide to offer an enriching and welcoming experience to the profession. Understanding the elements of this support system – via the culture of the profession is an underlying purpose here.

Once clarified the scope of this investigation we can emphasize the role of the first-year engineering experience. This first-year constitutes the first exposure to engineering communities of practice, for example, through topics like "introduction of mathematical and scientific concepts in the context of engineering applications" as engineering educators have called and studied these topics before [29, 36, 37]. The cultural conceptualization of this manuscript connects directly to the curriculum, specifically this first-year engineering experience. First-year engineering programs have been investigated via the taxonomy of first-year engineering curricula. Various researchers have documented the wide variety of approaches to the first-year engineering experience across the United States and have published taxonomies of outcomes common to programs [38–40]. Such taxonomies have identified the following outcome factors: communication, engineering profession, mathematics skills, design, global interest, professional skills, academic success, and engineering tech/tools. The institution that constituted the site for this study adopted the first-year engineering experience in the form of Fig. 1. The eight dimensions shown represent the major elements of the culture; base knowledge, practices, and values, as included in the curriculum or the support system at the institution. The example of engineering sciences aforementioned can be understood as the mathematical and physical modeling dimension in the diagram.

The Accreditation Board for Engineering and Technology (ABET) operationalize these cultural dimensions through the observable outcomes that engineering students are expected to exhibit. Table 1 displays the equivalency between ABET outcomes and the first-year engineering dimensions.

2.2 Enculturation to Engineering During the First-Year Experience

The institution examined here operationalized the traditional content of the engineering culture and assimilation of its practices and values in two introductory semester-long courses: Foundations of Engineering I and II. The course goals, followed by the equivalent cultural engineering dimensions, are listed as follows:

Table 1. Comparison of ABET Outcomes and First-Year Engineering Curricular Dimensions [41]

ABET Outcomes	First-Year Engineering Dimensions
• an ability to identify, formulate, and solve complex engineering problems by applying principles of engineering, science, and mathematics	• math and physical modeling and problem solving
• an ability to apply engineering design to produce solutions that meet specified needs with consideration of public health, safety, and welfare, as well as global, cultural, social, environmental, and economic factors	• engineering design
• an ability to communicate effectively with a range of audiences	• engineering communications
• an ability to recognize ethical and professional responsibilities in engineering situations and make informed judgments, which must consider the impact of engineering solutions in global, economic, environmental, and societal contexts	• engineering ethics and engineering profession
• an ability to function effectively on a team whose members together provide leadership, create a collaborative and inclusive environment, establish goals, plan tasks, and meet objectives	• engineering teamwork
• an ability to develop and conduct appropriate experimentation, analyze and interpret data, and use engineering judgment to draw conclusions	• algorithmic/computational thinking
• an ability to acquire and apply new knowledge as needed, using appropriate learning strategies	• engineering profession

Foundations of Engineering I – Course Goals:

1. Describe the engineering disciplines at the institution and the interrelationships among them as well as know what graduates of at least three disciplines of engineering do. (Engineering Profession)
2. Individually, or as a member of a technical team, understand and apply a structured engineering problem solving using a design process. (Teamwork, Problem Solving, Engineering Design)
3. Develop algorithmic thinking by implementing simple algorithmic forms of engineering models/problems using MATLAB. (Algorithmic Thinking)
4. Communicate technical information via written, oral, and visual communication tools. (Engineering Communications)
5. Recognize the advantages and challenges of problem solving using a team. (Teamwork, Problem Solving, Ethics)

Foundations of Engineering II – Course Goals:

1. Describe, in greater depth, the engineering disciplines at the institution. (Engineering Profession)
2. Individually, or as a member of a technical team, apply knowledge of a structured engineering problem solving process, engineering fundamentals and basic engineering science concepts to create more advanced engineering criteria, discovered using a design process, that satisfy a problem of engineering interest. (Teamwork, Math and Physical Modeling, Problem Solving, Engineering Design)
3. Design processes to communicate technical information orally and visually. (Engineering Communications)
4. Implement complex algorithmic solutions to engineering problems/designs using an appropriate computer tool (Excel, LABVIEW, and MATLAB) and be able to explain your rationale for your choice. (Algorithmic Thinking, Problem Solving, Engineering Design)
5. Synthesize your knowledge of effective and ethical membership on a technical team (i.e., teaming skills) to refine your conduct as a member of the team. (Teamwork, Ethics)
6. Exhibit a work ethic appropriate for the engineering profession. (Ethics)

By exploring how students' perceptions of enculturation to engineering change over time, this study will bring to light the process of theory-building while establishing a theory of enculturation using the methodological approach described below.

2.3 Theory-Building in Engineering Education

Theory is a "set of well-developed concepts related through statements of relationship, which together constitute an integrated framework that can be used to explain or predict phenomena" [42, p.15]. Reynolds, Rosenberg, and Mathews have separately stressed the causal and relational notions implied in the use of terms, such as explanations, predictions, or understandings, when defining theory or science [43, 45]. Therefore, at the heart of a theory, there is a cause-and-effect and/or a relational process to be described. The way in which humankind has elaborated these descriptions has evolved over time. Kuhns's structures of scientific revolutions illustrate this evolution via the description of paradigms, such as "Ptolemaic astronomy (or Copernican), Aristotelian dynamics (or Newtonian), corpuscular optics (or wave optics), and so on" [46, p. 10].

Modern theory-building, understood as the process of elaborating theories, is a topic of interest, specifically in applied and behavioral sciences [47-50]. Engineering education research in particular has repeatedly called for ways to include the process of theory-building [51, 52]. However, most engineering education research has applied theories in a confirmatory fashion and only a few grounding theory studies have clearly delineated the conceptual development and operationalization phases [53–55]. This study thus contributes and expands existing research.

Theory-building has its roots in epistemological approaches to science that recognize two philosophies: the "inductivist," also called "research-then-theory" approach and the "falsificacionist," also known as "theory-then-research" approach [43, 56–58]. The inductivist or research-then-theory approach involves observing a phenomenon, describing and measuring its characteristics in a variety of conditions, identifying patterns of data, and identifying a theory that fits the patterns [43]. In contrast, the fasificationist or theory-then-research approach involves a conjecture or hypothesis to be refuted or falsified via the design of a research plan to test it. Dubin recognizes six elements that affect all theory-building, which are shown in Table 2 [58].

The theory-building process employed here is related to Strauss and Corbin's and Charmaz and Thornberg's grounded theory, but has key differences [42, 59]. Grounded theory constitutes one method or research approach for theory-building, so it reflects elements and phases of the process but is mainly qualitative in nature. Theory-building encompasses all research approaches, quantitative and qualitative, that are conducive to creating, confirming, or disconfirming a theory and thus

Table 2. Elements in Theory-building-Source: Chalmers [56]

Units:	Concepts that constitute the building blocks of the theory and whose interrelationship are of relevance
Laws of Interaction:	Interrelationship of the units
Boundaries:	Limiting values on the units compromising the model
System States:	The recognition of the characteristic values of the units when the system is in a particular state
Propositions:	True statements about a model when the model is fully specified in its units, laws of interaction, boundaries, and system states
Empirical Indicator:	Operation employed by a researcher to secure measurements of values on a unit
Hypothesis:	Predictions about values of units of a theory in which empirical indicators are employed for the named units in each proposition.

advancing science. Lynham proposed the general method of theory-building process for applied sciences, which involves five phases [48]. These phases should be followed in order in the first iteration although in subsequent refining may be performed out of order.

Conceptual Development involves the composition of beginning ideas that provides a first understanding of the phenomenon. *Operationalization* is the fully expressed relationship between the conceptual development and the practice. *Confirmation and Disconfirmation* involves the testing of the operationalized theoretical framework against the practice. *Application* is the practice component of the general theory-building research method in real world situations in which similar phenomena are identified. And *Continuous Refinement and Development* can be best understood as the "ongoing study, adaptation, development, and improvement to ensure that the relevance and rigor of the theory are continually attended to" [48, p. 234]. Fig. 2 shows the process of theory-building adapted from Lynham, which emphasizes practice. Since engineering education is an applied field, practice in the engineering classroom is expected to inform and be informed by theory-building –evidenced based practices. In addition, this general method never considers an applied theory "complete but rather true until shown otherwise" [48, p. 230]; therefore, the continuous refinement and development phase is, rather, a cycle that encompasses all other phases. This study will present a theory of enculturation at the levels of conceptual development, operationalization, and confirmation/disconfirmation.

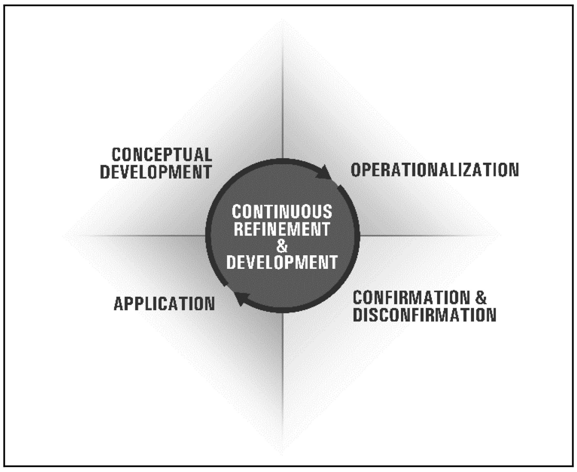

Fig. 2. Process of Theory-Building – Adapted from Lynham [42].

3. Method

The methodological strategy used was a sequentially mixed approach, using quantitative and qualitative techniques [60]. The prior findings published in the six papers aforementioned informed the development of the semi-structured interview protocol and the concepts that serve as base of analysis. The following paragraphs will describe this method in detail.

3.1 Participants and Data Collection

During the Fall of 2018 a set of focus groups and interviews took place with eight participants in their sophomore and junior years. The participants had taken the two foundational courses. The invitation to participate was open to all undergraduate engineering students, other than freshman, with 14 students responding to the invitation but only eight attending the sessions that would best accommodate their schedules. The eight students who attended the focus group sessions were mainly students with a long-standing relationship with the lead investigator or the research assistants who helped to conduct the focus groups. The invitation was for focus groups but, for two of the focus groups, only one participant attended the session transforming those focus group in interviews. Table 3 shows the participants' demographics and Table 4 shows the pseudonyms used in this study. Appropriate Institutional Review Board approval and consent forms were collected at the beginning of the sessions and a copy of the first-year course syllabi was provided prior to the meeting as a reminder of the content to be discussed. An incentive in the form of a coffee shop gift card was given upon participation. The focus groups and interviews were audio recorded and

Table 3. Demographics of Participants in Focus Groups

Category	Subgroup	Focus Group 1	Focus Group 2	Focus Group Int. 3	Focus Group 4	Focus Group Int. 5	Total
Gender	Female	2	1	1	1	0	5
	Male	0	1	0	1	1	3
Race/ Ethnicity	Hispanic	1	1	0	1	0	3
	Asian	0	0	0	1	0	1
	AI/AN	0	0	0	0	0	0
	Black	0	0	0	0	0	0
	White	1	1	1	0	1	4
	Multiracial	0	0	0	0	0	0
Grand Total							8

Note. AI/AN is American Indian and Alaska Native.

Table 4. Pseudonyms assigned

Group-Interview	Participant 1	Participant 2
Focus Group 1	Carmen	Amy
Focus Group 2	Harry	Susana
Focus Group-Interview 3	Liz	–
Focus Group 4	Monica	Sami
Focus Group-Interview 5	John	–

later transcribed utilizing professional transcription services.

3.2 *Semi-Structured Interview Protocol*

The research team, composed of the lead researcher and undergraduate research assistants, developed an interview protocol that best reflected the lessons learned from the prior studies. There were two interviewers who utilized a base interview protocol (Appendix A) but adapted the questions based on the answers participants provided. The interview protocol considered questions that included the following main ideas: (1) distinction of engineering culture versus other professional cultures (e.g., medicine or law), (2) perceived changes in their understanding of engineering dimensions since their first-year, (3) sense of belonging to engineering and/or a specific community, (4) request for specific long impact of certain dimensions such as problem solving or algorithmic thinking (based on the answers given), (5) supplemental instruction participation and impact, and (6) recommendations for first engineering experiences.

3.3 *Interpretive Approach*

The interpretive mixed method approach was selected because of its flexibility for gauging the frequency that a certain theme or concept is expressed by participants as well as the opportunity to form new themes [60, 61]. The interpretive techniques utilized were content analysis for the quantitative piece and open coding for the qualitative portion. The content analysis piece involved an exhaustive analysis of transcriptions utilizing an initial codebook that adhered to the eight curricular dimensions of engineering enculturation (Fig. 1). Three coders were involved in the analysis of content, reaching an inter-rater reliability coefficient of 0.80 through multiple conversations and iterations on how to apply the codebook with the lead investigator [62]. For the open coding, an investigator joined the three coders to conduct ‘‘inductive-generative-constructive-subjective analysis’’ [61, p. 335], or open coding, finding the additional themes shown in Table 5.

More mechanisms to ensure trustworthiness, or quality of the research, included prolonged engagement, peer debriefing, audit trail, reflexive journal, and triangulation. The prolonged engagement of the research team members with most of the participants established a level of rapport that allowed the conversation to flow casually and with honest answers. The peer debriefing occurred at weekly meetings of the research team in which the interview protocol was formulated, the meetings were scheduled and conducted, and the data was analyzed. An audit trail of emails, notes, and shared documents is still under the researcher’s possession in a shared drive. The principal investigator maintains a notebook for her projects, and a reflexive journal of the ideas picked from conversations, literature, and observations is dedicated to this project. Given the different perspectives employed, the analysis had triangulation mechanisms that provided confirmability and dependability of results.

4. Findings

4.1 *Content Analysis*

In order to capture how the eight curricular dimensions of enculturation to engineering revealed themselves during the conversations, the researchers drew upon the direct content analysis performed on the transcriptions to obtain the frequency counts shown in Table 5 [62–64]. The most prevalent theme among the eight curricular dimensions was the engineering professions. This is unsurprising given that a major goal of the first-year program is to expose students to as many engineering disciplines as possible as well as the general elements that unify them all. Each focus group-interview had different second- and third-most frequent dimensions, yet teamwork was ranked high, evidencing the strong emphasis of teamwork during the first-year experience. Algorithmic thinking, math and physical modeling, and problem solving were also very frequently mentioned. The least-mentioned dimensions were ethics, engineering communications, and engineering design. Open-ended emerging themes including self-efficacy, community, identity, multidisciplinary, and supplemental instruction appeared in the thematic categories. A set of definitions and examples for each of these themes is provided in Appendix B.

It was puzzling that participants did not refer to engineering design as the distinctive activity in engineering during the interviews. During the peer debriefings, the research team suggested that the reason is that students had not yet been fully exposed to the capstone experience and thus have not associated the characteristics of engineering design to their problem-solving notions.

4.2 Examples of Analysis

The open-thematic coding of responses revealed indirect references to engineering design although they had not mentioned it directly. Carmen, Susana, and Liz made references to a very "unique" and "innovative" way of solving problems which can be associated with the concept of engineering design. As Table 6 shows, there was a convergence by these participants with the responses to the question "How would you define the features that make engineering a distinct group from other professions (e.g., medicine, law, business)?

Table 7 features selected responses to the question, "How have your views of engineering changed now that you're in your major compared to when you were a freshman?" Responses converged around the concept of the engineering professions. Amy, Liz and Sami referred to the specific engineer-

Table 5. Content Analysis-frequency counts of conversations

Themes	Focus Group 1	Focus Group 2	Focus Group-Int. 3	Focus Group 4	Focus Group-Int. 5
Dimension 1: Algorithmic thinking	16	9	10	10	13
Dimension 2: Teamwork	24	7	8	11	16
Dimension 3: Eng. profession	25	24	24	22	22
Dimension 4: Ethics	16	6	6	0	6
Dimension 5: Eng. communications	7	6	2	3	6
Dimension 6: Eng. design	2	6	6	8	8
Dimension 7: Math/physical modeling	6	12	8	6	9
Dimension 8: Problem solving	16	6	7	10	17
Self-efficacy	24	22	8	19	17
Community	26	8	10	20	5
Identity	17	14	9	16	23
Multidisciplinarity	8	4	2	1	4
Supplemental instruction	7	6	9	17	5

Table 6. Answers to the question related to the distinction of the engineering profession evidencing engineering design

Featured Responses per Focus Group-Interview to question on distinction of the profession
Carmen: "I guess what makes us different is probably the way we think about things. That problem solving, most people go into engineering because they love problem solving and challenges, more so than other professions. You have to be really innovative and approach problems and be able to figure out a solution versus other professions, you have procedures that you go through. Engineering, it's more like you kind of have to figure it out as you go. You can have general guidelines to be an engineer. You can't already know what you're supposed to do because that wouldn't be engineering. Maybe like that."
Susana: "I think [engineering is] really unique because of it's just the way that if you look at something, I think an engineer will look at something specifically in a different way. Even though doctors and lawyers, any other profession look at it, look at different stuff, we engineers, I think we look at it and then actually go in depth with it, actually realize what's wrong and actually the mindset. The mindset's actually different. I think it's the way you look at it and how you actually solve it, how you actually interpret it. It's actually what makes an engineer and the way they think. I think it's really unique, honestly and so different than other [fields]."
Liz: "I think a big [thing that distinguishes engineering] is problem solving and a lot of other fields, like lawyers or doctors, they have one case right in front of them at the time and they fix that problem. They might be innovative in that solution, but there's typically already a set of guidelines and practices for that. But I feel with engineering it's more of a, what's the bigger picture? What are these bigger problems that we can solve? Innovation within a specific field I guess."

Table 7. Answers to the question related to the changes in their views of engineering

Featured Responses per Focus Group-Interview on changes in view of engineering
Amy: "I'm trying to think. So, I came into college wanting to be a chemical engineer, then realized very quickly that there are other options. I think coming in, I had a very narrow idea of what engineering was. I was tour guide this summer for the residence halls and I would get asked about engineering a lot. The ones that people always knew of were chemical, electrical, mechanical, aerospace, and civil. A lot of people don't realize that there are ones outside of that, I didn't realize that there was one outside of that. I think that in terms of my understanding of the applications of engineering, it's definitely expanded very much."
Liz: "I feel like I didn't, I guess I just blindly jumped into engineering. I didn't really know too much about engineering. And then since then learning more about different jobs and what actually the daily life of an engineer looks like. And then I guess in my courses, I didn't know that there was so much that I didn't know about math and science and engineering."
Sami: "You have to work with students a lot of times with projects because, if it's a class project, you can't do it by yourself sometimes. Yeah, the way I would see the difference is that freshman year, you've had a hard time with other people. They have many different mindsets, ideas in what they're gonna do. You don't know what they're thinking most of the time. It's just unpredictable, whereas now, when you're in a program, you get an idea what people are gonna do, what they're gonna think, their time schedules and everything. The way I view it now is we all have some kind of role we have to play. We know our own roles, I guess if that makes sense."

ing disciplines they were exposed during their first-year (when they were part of the general engineering cohort), their diversity, and also the standards of professional practice as they see them in their majors once they've progressed.

4.3 Open Thematic Analysis

Engineering education research has addressed each of the eight dimensions in Table 5 as separate areas of inquiry. Informed by prior studies under this project's umbrella, the open coding analysis produced the additional themes seen in Table 5. A description of findings related to these themes is provided as follows.

4.3.1 Self-efficacy

Multiple participants made statements that evoke Bandura's concept of self-efficacy, a subject of considerable research in STEM education [65]. For example, when asked to rate her engineering identity on a scale of 0 to 10, Carmen said that she felt like a seven or an eight. She acknowledged that another student had reacted negatively to it, seeming surprised by her confidence, but that she felt she had earned that confidence:

> "I don't know, I think just like, doing research and actually applying the knowledge that I've learned gives me a lot of confidence. Maybe it's false confidence, who knows. But you know, still has the same effect of motivating me to complete my degree and things. Obviously there's still more things I need to learn which is why I'm not a graduated engineer yet. But I think especially because this semester's been really hard, how I'm handling it and how I'm organizing myself and my priorities and my goals and stuff. I feel like wow, I really can do this. That's why I think I'm ready to enter the workforce. Definitely not now but once I graduate I think I would be a successful engineer, but I don't know."

Carmen had also shown confidence in her eagerness to answer the question, offering immediately to be the first among the focus group to answer.

4.3.2 Community

Community building and a sense of belonging was prevalent theme throughout the umbrella project [66]. Very early in this project, it was clear that students who were exposed to formal and informal student or professional organizations, or who sought support with peers and mentors, felt more confident and attuned with the demands of the engineering profession. For example, Monica, who early in the focus group mentioned that she did not feel welcome in a Hispanic organization, asserted that her sense of belonging came with the community of Women in Engineering. When the interviewer asked the focus group about communities that made them feel a sense of belonging she said

> "I think that just made me feel like . . . When I was thinking about which [engineering discipline] should I choose, I was thinking about all the things that I've decided that I liked, and I realize that mechanical is definitely the one for me, I think [referring to her professional community]. Then I was thinking Society of Women Engineers, I'm really into that. At first, I went in knowing that I wanted to be in that because I was in other girl orgs in high school and stuff, but I didn't really feel like I belonged until this one chick one day said, 'Are you going to the meeting? Because I don't want to go if you don't go,' and I was like, 'Oh, my goodness. Somebody actually wants me to be there and help them plan things.' They actually want me to be the one sitting next to them, and I felt like I belonged then."

4.3.3 Identity

Several participants referenced engineering identity, another topic vastly investigated in research [35]. John, a privileged student whose father was an engineer, had said that one of the subjects he had not used since first-year was statistics. When the interviewer asked the group what recommendations they would make for the introductory first-year courses, he said,

> "If there's something to cut – I took away the least from doing statistics. I've never taken a proper statis-

tics class. All I know from statistics is just the tidbits that you get in different classes. They kind of talk to you about statistics a little bit, but I've never taken a proper statistics class. So, I don't know. Yeah, statistics was probably the least thing I took away from that. But I'm trying to think of anything else. I don't know. They threw a lot of work at you. I thought that was good. I do remember that. It was challenging. I think it did a good job of showing some students they didn't want to be engineers, that maybe they weren't cut out for it."

4.3.4 Multidisciplinarity

Since the first-year experience in the institution presents a very rich assortment of topics, including exposure to multiple disciplines, all participants offered their own perspective about pursuing a particular specialization later in college. Harry, who had already been recruited by the Air Force, chose a non-traditional path for his engineering practice. Due to the multitude of multi-disciplinary opportunities in the institution, he enrolled in a business engineering undergraduate program managed by the School of Business and the College of Engineering. His is an example of the college of engineering's multidisciplinarity, taken to the next level beyond the confines of the college of engineering. He said,

"You're [meaning students in his program] invited to all of the other aspects so you're kind of qualified in both the technical aspect and then the business aspect as well. Which I just see myself doing because my personality type, I don't love office jobs. I don't like sitting in front of my computer when I'm doing homework, it's the worst thing in the world. I'd rather be outside doing something else. After my five years or whatever in the Air Force, I don't want to be able to have no option other than falling back on my engineering degree because there's only however many years in the Air Force and then I get out and would I come out of [the institution] with is what I've got to work with to market myself to companies or wherever I want to go."

When the interviewer asked him if he saw a distinction between the pure technical work and more managerial business aspect, Harry said yes, acknowledging that his major has blended these two aspects.

4.3.5 Supplemental Instruction

At the time the data was collected, the first-year engineering experience was piloting a supplemental instruction program (SI). This program, originated and managed globally by the University of Missouri-Kansas City-International Center, and supervised locally by the institutions' student success center, involves approximately three hours outside class led by students, usually undergraduate teaching assistants who have taken the class [67]. These hours are divided into 1 hour sessions, devoted to work problems and exercises related to the content of the SI class lectures, which the undergraduate teaching assistants also attend. Previous publications showed the impact of this supplemental support, which led to its inclusion in the protocol and then becoming a thematic category [5]. Liz spoke very highly of the program. She said,

"I guess they would expand on what I learned in lecture and I feel, sometimes in lecture the professor I had was pretty soft spoken and if I didn't sit directly in the front then I probably wouldn't pay attention. I think sometimes I'd be like, oh, we learned something about something today. Then I have no clue. Then I would go to SI and I'd be like, oh, okay, this makes sense now. This is approachable. I'd probably stayed behind things, I learned more in lecture, but then going to the SI sessions, actually doing the practice problems in there. I think I went to the universal accounting equation, I was so confused until I went to SI. A lot of this statistic stuff in [Engineering II], that sort of thing. It was stuff that in class I was like, yeah I kind of know this and then I would zone out and then I would look at the homework and be like, nope, don't know this. Then SI would definitely help me with it."

5. Discussion

5.1 Macro-analysis of Themes

The macro-analysis of themes revealed two major categories. The first, the extrinsic category or external factors for enculturation, can be defined as those procured and mandated by the support system via prescribed activities listed in the curriculum, course goals, and daily lesson plans. These are the eight curricular dimensions of the first-year experience which also mapped to ABET outcomes.

The second, the intrinsic factors, are those factors that involve students choosing whether to internalize their enculturation using initiatives supported by the system but not made mandatory, such as attendance to supplemental instruction or adhesion to student/professional organizations (e.g., Women in Engineering, SHPE, IEEE student chapter, Corps of Cadets). These intrinsic factors are (1) supplemental instruction, (2) multidisciplinarity, (3) community, (4) self-efficacy, and (5) identity. The umbrella project, as well as others' engineering education research, shows that these factors are critical in the success of underrepresented and underprivileged groups.

Using Godfrey's theoretical model for cultural analysis (amended from Schein [22]), this manuscript proposes the model on the righthand side of Fig. 3. In Godfrey's model [21], shown on the lefthand side of the figure, there is an element of hidden curriculum that the newcomer has to discover and assimilate during the three-level professional assimilation. The updated model emphasizes how the support system offers enculturating opportunities to learn this hidden curriculum. The dis-

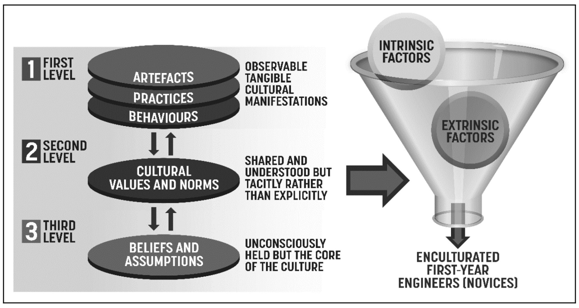

Fig. 3. Left-Theoretical model for cultural analysis-Adapted from Godfrey's [21] and Right-Theoretical model for enculturation to engineering during the first-year engineering experience.

cussion section in this manuscript offers the perspective on intrinsic-extrinsic factors that is more attuned to the desired outcome, the enculturated engineer.

5.2 Integration of a Theory of Enculturation

The last research question of this study examines the way results exhibit a Theory of Enculturation. The following paragraphs will describe how the results reveal this theory in the sense that they provide evidence of relationships and causation between the elements.

Table 8 reflects Chalmers's elements in theory-building for this specific case beginning with the **units of the theory** represented by the eight cultural dimensions of enculturation (extrinsic factors) as well as the five intrinsic factors: self-efficacy, community, identity, multidisciplinarity, and supplemental instruction. The interpretive approach in this investigation afforded the opportunity for creating negotiated meaning between participants and the research team, thus operationalizing these elements.

As established in the motivation of this study (intro section), because of the day-to-day challenges of first-year engineering instructors who had to navigate through multiple curricular changes in a brief period, the effect of the support system in the process of enculturation was paramount in the conceptualization of this model and the units of the theory. The importance of the support system speaks to and from the instructors about those aspects that can be under their control.

After obtaining funding, the conceptual development and operationalization of the theory from the earlier works [5] revealed some precursor elements that resulted in the intrinsic and extrinsic units of this theory. The findings in this manuscript confirm these units.

Finding the **laws of interaction**, or the interactions between the units of the theory, proved to be more complicated than anticipated. Given Godfrey's earlier work and the notion that a culture consists of knowledge, practices, and values shared by a community, a Venn Diagram of the type of Fig. 4 was developed. The separation in the basic domains of a culture – knowledge-practice-values (KPV) – required several iterations and discussions because almost all factors involve a combination of base knowledge, laboratory, practice and values of professional practice. The standalone themes were placed external to the Venn diagram, reflecting the emphasis this investigation has placed on the intrinsic (e.g., identity formation) and extrinsic factors (e.g., curricular intervention). In other words, the day-to-day challenges engineering instructors experienced, the initial motivation for this study, translated into an effort of characterizing the support systems and external mechanisms that better aid in the enculturation of engineering students. It is complicated to infuse the intrinsic processes such as identity formation, sense of belonging, and self-efficacy through an educational intervention, but they are important to enculturation. The institution recognizes these theoretical units and supports student organizations, supplemental instruction, and other mechanisms that are not necessarily part of the mandatory first-year experience. Given the multitude of institutional approaches to the

Table 8. Building a Theory of Enculturation to Engineering

Units:	Intrinsic and extrinsic factors as described in curricular dimensions and other themes.
Laws of Interaction:	Interactions between intrinsic and extrinsic factors, the dimensions and themes of enculturation, as they represent the knowledge, practices, and values of the community of practice (Fig. 4).
Boundaries:	Experiences and lessons in curriculum that occur in the first-year only.
System States:	Inclusion or exclusion of intrinsic and extrinsic factors (non-mandatory and prescribed curriculum activities).
Propositions:	ABET-accredited programs and programs with initiatives that foster intrinsic enculturation can assimilate students to engineering profession during their first-year in college.
Empirical Indicator:	Indicators identified in identity inventories, computational thinking diagnostics, and other engineering education instruments to measure the units [35, 68–69].
Hypothesis:	Students who navigate the first-year engineering experience and internalize factors coming from prescribed curriculum and elective opportunities provided at the institution are getting enculturated and can potentially transition to the professional engineering world.

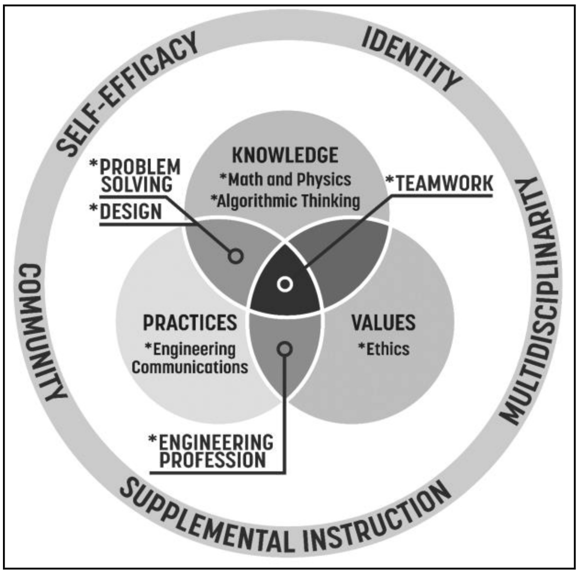

Fig. 4. Knowledge-Practices-Values Model for Theory of Enculturation to Engineering.

intrinsic factors of enculturation, it is understandable that Godfrey found it difficult to create a characterizing/comprehensive model of enculturation to engineering that all instructors could use.

The **theory boundaries** were the limitations that the first-year engineering curriculum imposes. This became clear in this manuscript because of students' failure to recognize the engineering design conceptualization after their introductory courses. Vertical curriculum design activities such as entrepreneurship or service-learning challenges for multi-classification/level groups (e.g., I-Corps or EPICS) might address this omission. However the participants of this study were not exposed to such experiences.

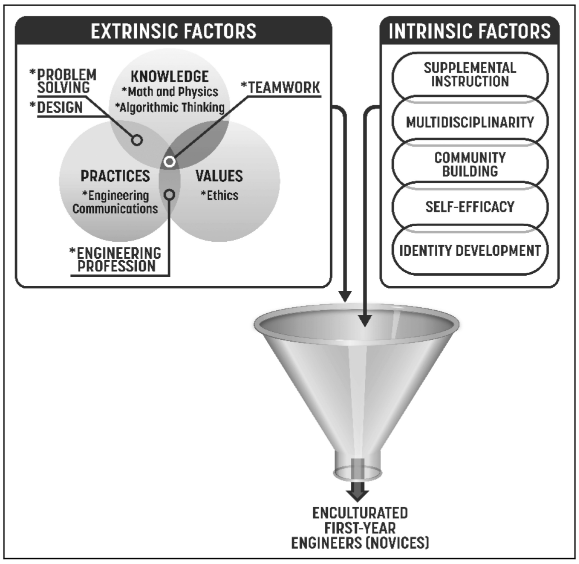

Fig. 5. Theoretical Proposition of Enculturation to Engineering via First-Year Experience.

For the **system states,** the (non)inclusion of experiences through curriculum and mandatory initiatives played a significant role. For example, the first-year experience of the institution organizes multiple presentations on different topics, bringing members of industry to campus in order to expose students to as many disciplines as possible. The first-year program requires that students attend a number of such presentations as well as watching videos (prepared by the different departments) shown at the beginning of class. Participants of this study mentioned the value of these presentations and videos, in some cases, as motivators to a change of their initial major of interest. Since these are programmatic mandatory experiences, they were included in the characterization of engineering professions in the first-year engineering dimensions. Therefore, in the analysis of systems states, the dimension for engineering profession was included as part of the extrinsic unit of the theory. If these experiences had not been mandated, they would have been considered part of an intrinsic factor. Also, for initiatives that other institutions might have (either mandatory or not), the system states would be the mechanism to reveal their impact in the enculturation model.

The overall **theoretical proposition** that the results of this investigation offers is that a theory of enculturation manifests in what first-year ABET accredited engineering programs do – in theory. This means that programs complying to ABET requirements are expected to produce engineers using all the elements in the outcome criteria, or what is called here, the enculturation dimensions or extrinsic factors. In addition, by combining the eight engineering enculturation dimensions in the form of "ingredients" and under the right 'instrinsic' circumstances, such as community building, self-efficacy, or supplemental instruction, it is expected, based on the theory, that students will be enculturated. The funnel in Fig. 5 represents this proposition.

The **empirical indicators** of this theory have been developed by the multitude of instruments and diagnostics on each of these dimensions and themes. For example, there is an engineering identity instrument, a visualization instrument, and a computational thinking diagnostic already published in the engineering education field [35, 68–69]. These instruments have captured in very specific metrics and values, the degree of enculturation to each of these units' dimensions and themes. They have explicitly operationalized the concepts behind them.

Finally, the **hypothesis** of this theory, or the predictions that can be drawn from the propositions in measurable units, is that if institutions procure a support system that fosters outcomes in the form of the eight dimensions of knowledge, practice, and values, and if they support intrinsic development of self-efficacy, identity, community, multidisciplinarity and supplemental instruction, students are very likely to transition smoothly into the professional practice of engineering.

Although ABET is an international accreditation agency, international audiences might assimilate the results and this theory in the form of their own accrediting agencies. Thanks to international professional organizations such as IEEE or ACM, these accrediting agencies implement global standards for practice making this model of enculturation usable and reliable in contexts outside of the United States.

5.3 Limitations and Implications

The limitations of the study include the transferability of results to specific cultures at other institutions that may have different curricular approaches or fewer resources such as supplemental instruction, including those outside the United States. Since students in the sample were sophomore and junior level students, the study was also limited to this population. The implications for future research might include longitudinal follow-ups with some of these participants, including the research assistants (interviewers and research team), who are now practicing engineers. It may also include a critical view of the units of this theory since, as it has been established, mechanisms such as meritocracy and other normative narratives are well entrenched in the culture of engineering institutions [70]. Yet first, it is understandable that such units must be fully identified and characterized and this manuscript, through its enculturation perspective, has such intention.

6. Conclusions

Building from preliminary work related to the way foundational courses facilitate enculturation of first year engineering students and their perceptions of the engineering outcome factors, this manuscript highlights the perceptions of students about their enculturation to engineering as they progress in their specific programs. Under an umbrella project this manuscript answers the remaining two research questions of this umbrella project:

RQ3-How do students' perceptions of enculturation to engineering change over time?

RQ4-How do the findings reveal a theory of enculturation?

Via focus groups and semi-structured interviews and a mixed method research approach, the study described changes in students' perceptions of engineering after their intro courses and developed a comprehensive theory of engineering enculturation. It is noteworthy discussing that although students obtain foundational concepts, such as design being the distinctive activity in engineering, once they progress into second and third year of the curriculum, they lose sight of these foundations. In this paper, it was proposed to incorporate vertically integrated curriculum to avoid losing sight of important foundational concepts after the first-year experience.

This research has also confirmed and unveiled practices-knowledge-norms that could've remained as hidden curriculum or role-modeling behaviors. That is, this research identified eight dimensions and five themes, 13 units in total that characterize a theory of enculturation to engineering during the first-year experience and has hypothesized on how these units operate to produce professional engineers. This model of enculturation emphasizes the extrinsic characteristics of the support systems in schools of engineering and departs from the intrinsic factors, widely researched with the theory of identity development, providing a framework that instructors and administrators can utilize when planning or modifying these support systems.

Although the study took place in the United States, it is expected that results have a degree of transferability to international audiences due to the equivalent and global accreditation mechanisms in place worldwide. This can also be expected from the international professional organizations overseeing many of the enculturating factors discussed here. It is also expected that this investigation invites the IJEE audience to join the conversation regarding enculturation to the engineering profession.

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Appendix A. Semi-Structured Interview Protocol

In your opinion and based on your first-engineering experience:

- What makes an engineer distinct from other professions (lawyers, doctors?)
- How has your view of engineering changed after Foundations of Engineering I and II?
- Depending on the responses provided until this point:
  a. How has your understanding of teamwork changed (how to improve)?
  b. How has your understanding of problem solving evolved? (break it down)?
  c. How has your understanding of algorithmic thinking evolved? (break it down)?
  d. Any other dimensions they presented

- How do you feel that you belong to the engineering community? (students, major?)
- How have your interactions with others at TAMU (inside or outside engineering college) has made you feel as an engineer?
- If you were to scale from "0–10 your feeling as an engineer", what level would you consider yourself and why? (no Eng. to Professional Eng.)
  a. For your future, do you see professional-industry or grad school? What do you need to get to the 10?
- How helpful were the supplemental instruction sessions (SIS)?
- What recommendations do you have for the first-year engineering experience?

Appendix B. Themes in Codebook

Code	Definition	Example
Algorithmic Thinking	A logical, organized way of thinking used to break down a complicated goal into a series of (ordered) steps using available tools. Also associated with programming or coding	"I think probably as a freshman I would just jump right into it and get super overwhelmed and have no clue what's going on. But now being able to kind of break it down and look at it and steps and I don't know, I'm just thinking having a big coding project. I would probably have gotten into it and started typing something and be like, oh no this is all trash. I have no clue what I'm doing. I'm so confused. And I think now being able to think about little things that need to get done and how they lead to the big picture." **(Liz)**
Teamwork	To collaborate, communicate and coordinate efforts with a small group of people committed to a common purpose, performance goals for which they hold themselves mutually accountable.	"Team work is really important in engineering, more so than other things just because the problems we approach are a lot harder, so you can't solve it yourself a lot of the time. That's okay. You're not supposed to be able to. It's being able to collaborate and have that environment to bounce ideas off of each other to come up with a new solution." **(Carmen)**
Engineering Profession	To show how participants see themselves in engineering practice. It also involves understanding of specific engineering professional domains or specialties.	[referring to the presentations and videos they had to attend and watch] "I think that was a really good way to actually see the different types of majors because I really didn't come in {sic} and I was like okay I know there's a lot of majors but I want to find the right one for me." **(Susana)**
Ethics	To reflect critically about responsibility and the impact of decisions in engineering practice including the social outcomes.	"The engineering disaster projects, I think those are important. It makes you really aware that engineers have a lot of responsibility and things can go really wrong as an engineer. I think that the engineer that I strive to be is still pretty out there just because I don't think that I'm ready to have those responsibilities." **(Liz)**
Engineering Communication	To be competent in ways to communicate clearly the technical subjects to different audiences using a familiar language and to interpret technical information in written or oral formats.	"You're not always going to have an advertising team or some kind of PR team to help you figure out how to present your ideas and if you don't know how to communicate, it doesn't matter how good your idea is, how unique, how novel. You're screwed if you can't communicate." **(Amy)**
Engineering design	To understand the basic elements of the engineering design process.	"I'm always hard on myself. Honestly, I would say a four [discussing his feelings about a professional engineer] because I know I am a little bit harder on myself than probably most other people are . . . That's always something that kind of bothered me, is that I'm not good at design. I think part of that has to do with creativity. I don't know. I feel probably around maybe four or five. I'll have a co-op next semester, an internship, so I'll be able to know better by then when I actually get into the shoes of an engineer. But up until now it's just been very theoretical knowledge, and so I don't really feel like we've had the opportunity to apply it very much." (**John**)
Math/Physical Modeling	Capacity to characterize complex solutions through mathematics and science driven models.	"Okay, I already know how to do a Taylor series, here's MATLAB and you have to figure out the function. You have to figure out the grammar and how to submit a MATLAB file or run the function. All that at once would be difficult I think because it's introducing something completely foreign to a freshman, I think that'd be difficult." **(Harry)**
Problem Solving	Problem-solving is a cognitive and behavioral process that requires a high-level of thinking and consists of identifying effective solutions to needs or problems.	I feel like in engineering [foundations courses] they really walked you through solving the problem. They started off with task force one and then they added task force two, and in my mechanical engineering classes, they're not really giving us step by step. They like, "We want it done by this time." (**Monica**)

Code	Definition	Example
Self-efficacy	Self-efficacy is a person's particular set of beliefs that determine how well one can execute a plan of action in prospective situations (Bandura, 1977)	"I raised my hand once in class and I said this is a stupid question, and I was about to ask my question and he stopped me and he said, 'don't ever say that again. Don't ever say it's a stupid question.' Those have been the best professors I've had and the best learning environments I've had. Where people are like it's okay if you don't know, but you do need to learn this. And I will make sure that you learn it if you work with me. Those have been the best classes" **(Amy)**
Community	The students describe the time and space and group interactions to help them understand future practice and also social interactions with their community.	"I think there's probably two communities. So first would obviously be society of women engineers, I've been involved with them since my freshman year and it's been really rewarding to have that community of women who are in engineering, being able to support each other and give each other opportunities and stuff like that. I just found that that's probably the best community that I've ever been a part of, just kind of that sisterhood especially because it is so male dominated {engineering}, it's kind of nice" (**Carmen**)
Identity	It is the perception of students and their place in the profession or activity they identify with.	"Well, I actually don't have any friends that were in engineering. I mean, that were engineers and then decided to change. I actually am part of an organization, they're all engineers so I mean of course they're already in their major so I don't think they would actually drop engineering but I met a guy recently and he's a sophomore as well, chemical engineer but he's wanting to drop engineering. He told me because of not wanting to actually pursue chemical engineering no more but going just to math and science." (**Susana**)
Multidisciplinarity	A multidisciplinary view means an understanding of issues and an ability to apply simple concepts from multiple disciplines	"I think that having been in my major now I see that there are a lot more applications for engineering. Not in my major, but I'm in industrial engineering classes right now and I work for the industrial engineering department. There are a lot more applications for engineering than I think I initially realized. I could go work at a bank, I could go into healthcare, as an industrial engineer I don't have to go on to supply chain. That's my stereotypical idea of what an industrial engineer does, but I know that there's so many more applications for not just the material that I complete in the major, but also the problem solving mindset that engineering gives me. Which makes me valuable I think in not just engineering fields." (**Amy**)
Supplemental instruction	Supplemental instruction is a peer-led, academic assistance program that provides extra practice and clarifies misunderstandings of concepts related to a class.	"I would say maybe two or three per week [SI sessions] just because I did not have any experience with coding, so the first-time learning something it's like I never learned how to think about it this way or having to approach it differently. It was really difficult for me to understand and over time having to go into these SI sessions really helped me understand how I should probably approach it" (**Sami**)

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