Board 105: Exploring Enculturation in the First-Year Engineering Program (Year III)

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Theory Building in Engineering Education:
The Case of Enculturation in a First-Year Program

I. Introduction

Guidelines on scientific research are emphatic about the importance of theoretically informed research for the advancement of knowledge. They state that "studies that do not start with a clear conceptual framework and hypotheses may still be scientific, although they are obviously at a more rudimentary level and will generally require follow-on study to contribute significantly to scientific knowledge" (Shavelson & Towne, 2002, p.101).

Within the engineering education community, a community rapidly establishing itself in the education field, there is a vested interest in theories; the proof of this is the new criteria of the *Journal of Engineering Education,* which judges manuscripts by "relevant theories presented" (American Society for Engineering Education, 2008, ¶6). Theories informing studies are well represented by papers such as Brown et. al. (2018) who utilized a theory of conceptual change for students' explanations about mechanics of materials concepts. The theory-building process could be considered to be well illustrated within this community at the phases of conceptual development, operationalization and confirmation, and from the inductivist and the falsificationist perspectives. However, critical approaches to theories, meaning the challenging of the models that may lead to disconfirmation, are scarce.

This paper presents the process of theory building in general and for the specific case of an engineering education phenomenon. The second section provides a detailed explanation of what constitutes theory building. The third section is devoted to the explanation of an engineering education case. This section illustrates the theory building process for this particular case and also discusses implications for practice and research in human resource development and engineering education.

A. Theory Building

Theory is defined as 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" (Strauss & Corbin, 1998, p.15). Reynolds (1971) points out the causal and relational notions implied in the use of terms, such as explanations, predictions, or understandings when defining theory or science. Therefore, we can consider that at the heart of a theory, there is a cause-and-effect and/or a relational process to be described. We also know that the way in which humankind has elaborated these descriptions has evolved over time. Kuhns' 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" (1996, p. 10).

Modern theory-building, understood as the process of elaborating theories, is a topic of interest, specifically in applied and behavioral sciences (Egan, 2002; Lynham, 2002; Van de Ven, 2007). Theory-building has its roots in epistemological approaches to science in which two philosophies are recognized: the "inductivist," also called "research-then-theory" approach and the “falsificacionist”, also known as “theory-then-research” approach (Chalmers, 1982; Reynolds, 1971). The inductivist or research-then-theory approach basically involves the observation of a phenomenon, the description and measurement of its characteristics in a variety of conditions, the recognition of patterns of data, and the constitution of these patterns in theory (Reynolds, 1971). The fasificationist or theory-then-research approach, on the other hand, involves the notion of a conjecture or hypothesis to be refuted or falsified via the design of a research plan to test it (Chalmers, 1982). In this paper, we would like to emphasize that, whichever approach is taken in the process of building theory, there are elements and procedures in common that need to be identified. Dubin (1978) recognizes the following elements in theory building:

Table 1. *Elements in Theory Building* (source: Chalmers, 1982)

Units	Concepts which constitute the building blocks of the theory and whose interrelationship are of relevance.
Laws of Interaction	Interrelationships of the units.
Boundaries	Limiting values on the units comprising the model
System States	Understood as the “recognition of the characteristic values of the units when the system is in a particular state”
Propositions	“truth statement about a model when the model is fully specified in its units, laws of interaction, boundaries, and system states” (p. 160).
Empirical Indicator	“Operation employed by a researcher to secure measurements of values on a unit (p. 182) ”
Hypothesis	“Predictions about values of units of a theory in which empirical indicators are employed for the named units in each proposition (p. 206)”

Lynham (2002), on the other hand, proposed the process, named General Method of Theory Building, for applied sciences which involves five phases. These phases are not necessarily considered to “be pursued in the order they appear” (p. 230); however, we consider that for the first iteration, each step of the process should be present in the following 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 meaning the “translation or conversion of the theoretical framework to observable and confirmable components” (p. 232).
- 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 (as those characterized in the theoretical framework) are identified. “Application of the theory enables further study, inquiry, and understanding of the theory in action” (p. 233).
- Continuous Refinement and Development as a theory is never “complete” therefore it should require “ongoing study, adaptation, development and improvement to ensure that the relevance and rigor of the theory are continually attended to” (p. 234).

Figure 1 is a diagram of the process of theory building adapted from Lynham (2002). It is important to mention the emphasis given to practice in this general method. Since engineering education is an applied field, practice in the engineering classroom is expected to inform and be informed by theory building. In addition, this general method never considers an applied theory "complete but rather true until shown otherwise" (p. 230); therefore, the continuous refinement and development phase is, rather, a cycle that encompasses all other phases.

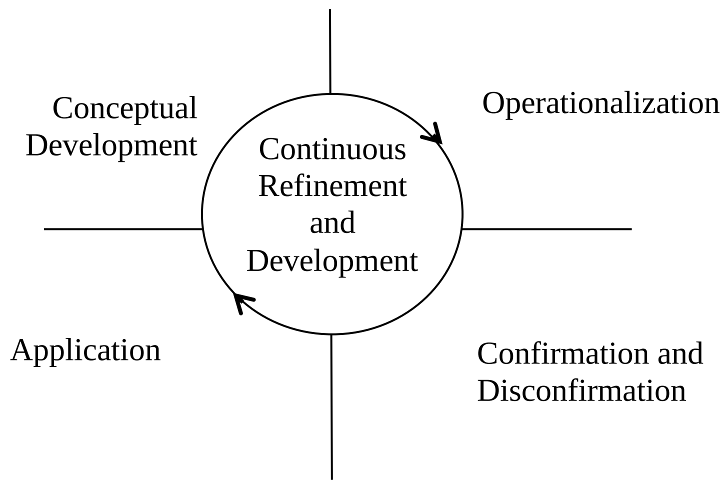


Figure 1. The general method of theory-building research in applied disciplines (Adapted from Lynham, 2002).

We must clarify at this point that theory-building is related to Strauss and Corbin (1998)'s grounded theory, but not entirely similar. Grounded theory, for our purposes, constitutes one method-research approach of theory building (meaning that reflects elements and phases of the process) that is mainly qualitative in nature. The process of theory-building is actually all research approaches conducive to confirm or disconfirm a theory, thus advancing science.

B. Engineering Enculturation

The need to form engineers via practice-like experiences has been widely established. Guidelines such as *Educating Engineers: Designing for the Future of the Field* (Sheppard et. al., 2008), the *National Academy of Engineering Grand Challenges* (NAE, 2018) or *NSF's 10 big ideas* (NSF, 2018) are emphatic in their implications about the new approaches to form engineers in a way that resembles the real-world experiences that students will be challenged with during their practice of the profession. Across the world and the nation, foundational engineering courses are being re-evaluated, common core courses have been established, and track-specific courses have been modified to encompass all basic skills that students should be developing since the beginning of the engineering program. Even a conference, the First-Year Engineering Experience (FYEE) Conference, is organized every summer, bringing together representatives of first-year engineering programs for the sole purpose of sharing innovative ideas, interventions, and lessons learned.

Since 2014, motivated by the day-to-day challenges faced with freshmen and transfer students, a team of professors at a southwestern institution have been investigating these practice-like approaches to form engineers, specifically in engineering foundational courses. They are investigating these foundational courses from an enculturation perspective. Enculturation can be understood as the "process by with an individual learns the traditional content of a culture and assimilates its practices and values" (Gove, 1966). Engineering enculturation can thus be defined as the process by which an engineering student learns the traditional content of an engineering culture and assimilates its engineering practices and values (Mendoza Diaz et. al., 2017). As opposed to identity development, enculturation pays specific attention to factors outside of the individual's personal culture conducive to its assimilation.

Supported by a comprehensive review of the literature involving first-year engineering courses, the eleven ABET Student Outcomes and the enculturation, they identified eight outcomes of the first-year engineering program at the southwestern institution: (1) Teamwork, (2) Engineering Profession, (3) Ethics, (4) Engineering Communication, (5) Engineering Design, (6) Math and Physics Modeling, (7) Problem Solving, and (8) Algorithmic/Computational Thinking. Figure 2 shows the engineering enculturation outcomes.

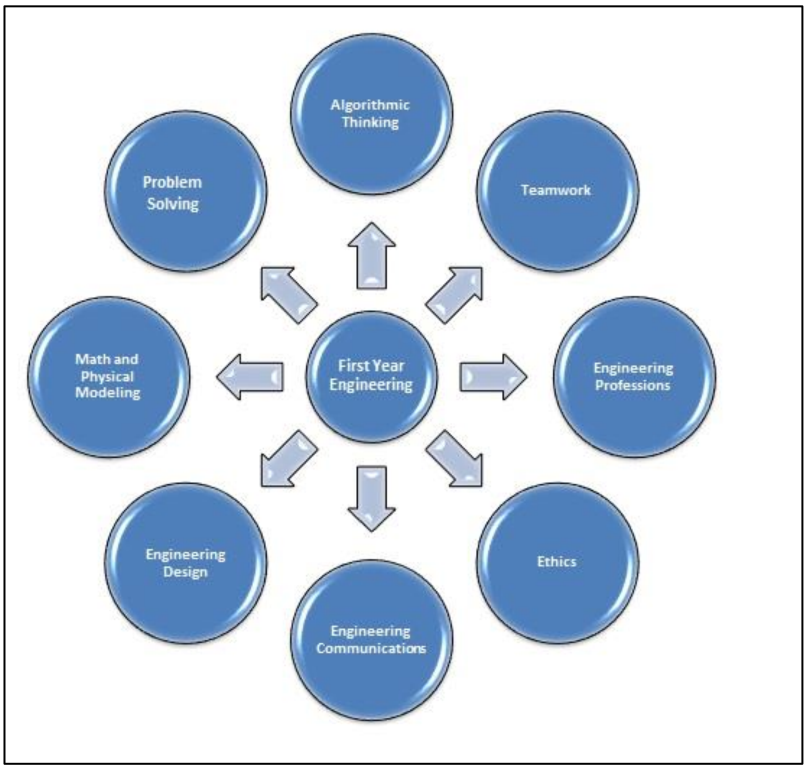
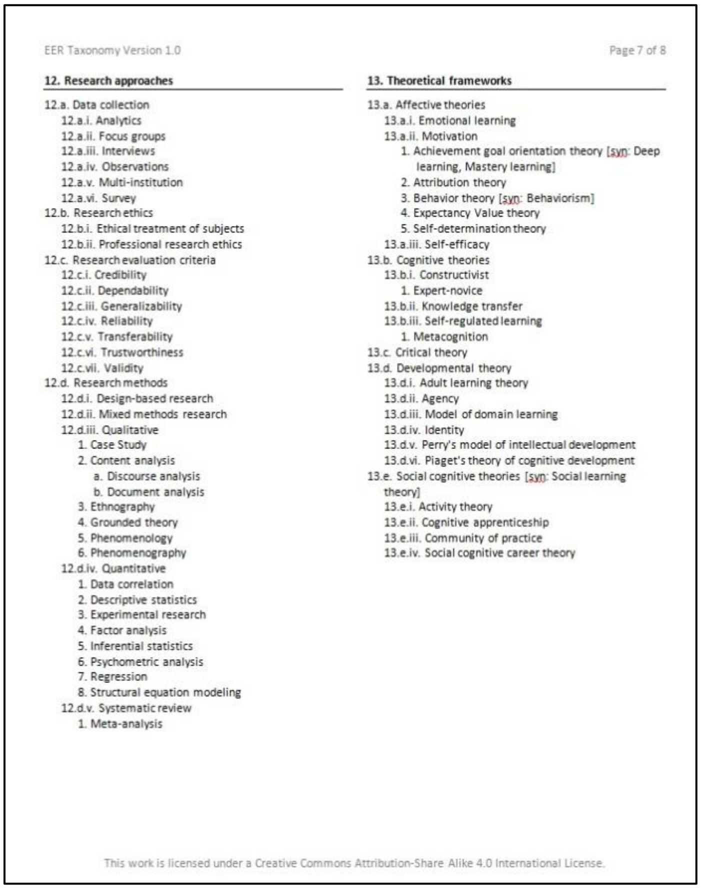


Figure 2. Engineering enculturation outcomes in the first-year engineering program

C. Taxonomies of Engineering Education

With the growing areas of research and with the purpose of avoiding duplication of effort and fragmentation of the field, a team of engineering education researchers elaborated a taxonomy, entitled *Engineering Education Research Taxonomy* (EER Taxonomy) (Finelli, 2018). This taxonomy comprises 455 terms arranged in 14 branches and six levels. Figure 3 provides a quick snapshot of the way the taxonomy is presented.


EER Taxonomy Version 1.0

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12. Research approaches

12.a. Data collection
  12.a.i. Analytics
  12.a.ii. Focus groups
  12.a.iii. Interviews
  12.a.iv. Observations
  12.a.v. Multi-institution
  12.a.vi. Survey
12.b. Research ethics
  12.b.i. Ethical treatment of subjects
  12.b.ii. Professional research ethics
12.c. Research evaluation criteria
  12.c.i. Credibility
  12.c.ii. Dependability
  12.c.iii. Generalizability
  12.c.iv. Reliability
  12.c.v. Transferability
  12.c.vi. Trustworthiness
  12.c.vii. Validity
12.d. Research methods
  12.d.i. Design-based research
  12.d.ii. Mixed methods research
  12.d.iii. Qualitative
    1. Case Study
    2. Content analysis
      a. Discourse analysis
      b. Document analysis
    3. Ethnography
    4. Grounded theory
    5. Phenomenology
    6. Phenomenography
  12.d.iv. Quantitative
    1. Data correlation
    2. Descriptive statistics
    3. Experimental research
    4. Factor analysis
    5. Inferential statistics
    6. Psychometric analysis
    7. Regression
    8. Structural equation modeling
  12.d.v. Systematic review
    1. Meta-analysis

13. Theoretical frameworks

13.a. Affective theories
  13.a.i. Emotional learning
  13.a.ii. Motivation
    1. Achievement goal orientation theory [syn: Deep learning, Mastery learning]
    2. Attribution theory
    3. Behavior theory [syn: Behaviorism]
    4. Expectancy Value theory
    5. Self-determination theory
  13.a.iii. Self-efficacy
13.b. Cognitive theories
  13.b.i. Constructivist
    1. Expert-novice
  13.b.ii. Knowledge transfer
  13.b.iii. Self-regulated learning
    1. Metacognition
13.c. Critical theory
13.d. Developmental theory
  13.d.i. Adult learning theory
  13.d.ii. Agency
  13.d.iii. Model of domain learning
  13.d.iv. Identity
  13.d.v. Perry's model of intellectual development
  13.d.vi. Piaget's theory of cognitive development
13.e. Social cognitive theories [syn: Social learning theory]
  13.e.i. Activity theory
  13.e.ii. Cognitive apprenticeship
  13.e.iii. Community of practice
  13.e.iv. Social cognitive career theory

Figure 3. An example of the *Engineering Education Research Taxonomy*

The EER taxonomy constitutes the most systematic organization of the field and in itself represents the process of theory-building. It comprises areas related to enculturation and theory building as part of the branches titled, *12. Research Approaches* and *13. Theoretical Frameworks*. As mentioned before, these branches encompass enculturation because (a) Enculturation can be understood as an alternative of identity development via assimilation to a culture, and (b) the process of identifying this new explanation or description of a phenomenon is theory building. Therefore, engineering enculturation is broader and richer framework that considers both inside and outside factors that may affect students' assimilation other than engineering identity.

In the following sections, the method in which the assimilation to the culture took place at the institution and the results of the first-year program intervention are shown, emphasizing how this advances the engineering education field in the form of theory building.

II. Methods

During the school year 2016-2017, almost three thousand students in the first-year engineering program at the southwestern public research university were asked about their understanding of engineering and enculturation to engineering via an online survey. The specific questions in the survey were:

1. Why do you want to be an engineer?
2. What is your understanding of being an engineer?
3. Define Engineering Culture in your own words.

Following the online survey, invitations to participate in focus groups were sent via the shared common announcement mechanism in the Learning Management System (i.e., BlackBoard). The invitation reached the same number of potential participants. The interview protocol included questions similar to the aforementioned and elicited further explanation from the participants. The interviews were recorded, professionally transcribed and a team of research assistants conducted the first analysis. The analysis technique utilized was content analysis to identify themes previously established (e.g., engineering enculturation outcomes) but also to identify new emerging themes (Patton, 2015).

A. Participants

The demographics of the nine focus groups are shown in Table 2. A total of 36 participants participated in the focus groups. During the fall of 2016, the majority of the participants were male and White. In spring 2017, the majority of the participants were female, White and Asian. The focus group participants were diverse with 53% female and 50% minority.

Table 2. Demographics of Participants in Fall 2016 and Spring 2017 Focus Groups

Cohort	Category	Subgroup	Focus Group 1	Focus Group 2	Focus Group 3	Focus Group 4	Focus Group 5	Total
Fall 2016	Gender	Female	4	3	1	1	0	9
		Male	2	0	4	2	3	11
	Race/ Ethnicity	Hispanic	2	2	0	0	1	5
		Asian	2	0	0	0	0	2
		AI/AN	0	0	0	0	0	0
		Black	1	0	0	0	0	1
		White	1	1	5	3	2	12
		Multiracial	0	0	0	0	0	0
Spring 2017	Gender	Female	4	3	2	1	—	10
		Male	1	0	1	4	—	6
	Race/ Ethnicity	Hispanic	0	1	1	1	—	3
		Asian	2	0	2	2	—	6
		AI/AN	0	0	0	0	—	0
		Black	0	0	0	0	—	0
		White	2	2	0	2	—	6
		Multiracial	1	0	0	0	—	1

Note. AI/AN = American Indian/Alaskan Native

III. Results

A. Pre-defined Themes and Emerged Themes on Engineering Enculturation

Tables 3 – 6 provide a summary of the frequency that pre-defined and emerging themes appeared in the transcriptions for the fall of 2016 and spring of 2017 focus groups. It is worthy to note that the participants in these focus groups were mainly first-year students attending their first (fall 2016) and second (spring 2017) college semester courses.

Table 3. Pre-defined Themes on Major Enculturation Areas in the Fall 2016 Focus Group Data

Pre-defined Themes	Focus Group 1	Focus Group 2	Focus Group 3	Focus Group 4	Focus Group 5
Algorithmic Thinking	8	23	6	30	18
Problem Solving	7	11	7	20	12
Math and Physics Modeling	7	9	2	11	9
Engineering Professions	6	2	2	1	6
Teamwork	4	10	12	11	11
Ethics	4	4	1	0	8
Design	3	6	5	13	2
Communications	2	9	10	13	26
Other	46	53	20	36	61

Table 4. Content Analysis for Major Enculturation Areas in Spring 2017

Pre-defined Themes	Focus Group 1	Focus Group 2	Focus Group 3	Focus Group 4
Algorithmic Thinking	3	9	19	16
Problem Solving	18	17	13	9
Math and Physics Modeling	8	13	11	10
Engineering Professions	6	1	3	6
Teamwork	21	6	23	36
Ethics	3	1	3	0
Design	4	9	10	4
Communications	17	8	20	19
Other	43	39	32	75

Table 5. Other Themes Emerging from the Fall 2016 Focus Group Data

Emerging Themes	Focus Group 1	Focus Group 2	Focus Group 3	Focus Group 4	Focus Group 5
Too much content for the course	9	3	0	13	13
Supplemental instruction was helpful	6	5	2	0	9
Coding was challenging	5	1	0	0	0
Obtained help from other sources	4	11	0	7	5
Teamwork was important	0	0	12	0	0
Chose engineering to help others	0	0	3	0	0
Course provided life skills	0	0	0	0	9

Table 6. . Other Themes Emerging from the Spring 2017 Focus Group Data

Emerging Themes	Focus Group 1	Focus Group 2	Focus Group 3	Focus Group 4
Too much content for the course	0	3	0	0
Supplemental instruction helpful	3	3	16	5
Coding was challenging	5	0	0	0
Obtained help from other sources	0	1	3	5
Teamwork was important	0	0	2	3
Compassion towards engineers	0	0	0	13
Provided life skills	19	0	0	23
Prior experience relevant	0	0	0	4
Learn how to fail	6	0	0	0
Chose engineering to help others	5	7	0	0

B. Examples of the Excerpts on the Themes

Some themes with excerpts are:

Algorithmic Thinking
Yeah I mean I think programming is taught so heavily this year because like you said, we are moving towards a lot of programming based stuff in our world. But I think at the base of it, it has to do with problem solving because a lot of people like me, I had zero coding experience at all going into this year and so I've had to read my Mat Lab book and look at stuff online and learn how to do stuff (Participant from Focus Group 4, 2016)

Teamwork
Yeah, I just had a question like overall for the course like how would you, I mean I guess, the hardest thing for me was just the teamwork because of how everyone – they didn't, and I mean I did get a formal apology from one kid because he was just like 'I don't have the skills to do almost anything,' you know? (Participant Focus Group 2, 2017).

Too much content for the course
Yeah. So it's kind of like you have to study for an exam that's the next morning, but you have one hour study group, and so you can't do that because you're at the study group, and [yeah you sit there] (Participant from Focus Group 5, 2016)

Compassion towards fellow engineers
I think, quite honestly, misery loves company. There have definitely been points in this last year where, I never even knew if this person was in engineering, but you see people walking across campus with a Lego box and part of your heart you're like, "I know what you're doing, I respect you sir, I tip my hat to you" (Participant Focus Group 4, 2017)

IV. Discussion

Preliminary results show that students' first understanding of engineering as a culture aligns to the way the question was presented (same terms and concepts provided to them during the explanation of engineering culture) but changed over time. That is, a comparison between Tables 4 and 6 shows that for their second semester, students acknowledged more themes than merely the ones presented to them, as was the case for their first semester. *Algorithmic Thinking* dominated the discussion during the fall of 2016, understandably as was the first semester they were exposed to programming while *Teamwork* dominated the discussion during the spring of 2017 given the fact that the team project constituted a big portion of their second semester course.

In terms of underrepresented students, Table 6, where a majority of participants were female, provides an interesting snapshot of themes relevant to this group. As literature suggests, for females, *Helping Others* is an important factor when choosing engineering. Other themes worthy noting were the acknowledgement of *Life Skills* provided by the course and *Compassion towards Fellow Engineers*. It is also important to note how the number of themes increased for the second semester, specifically of more altruistic type.

The analysis is currently at the stage of identifying minorities in terms of race and ethnicity to locate differences in perceptions towards first year courses.

Via these analyses, authors can claim that engineering enculturation occurs during the first-year engineering program in the areas pre-defined by researchers and in emerging areas identified by students. Authors can also present a case that engineering enculturation is a new theme in the taxonomies of engineering education research, thus advancing the field and instantiating the theory building process.

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