A Taxonomy for Introduction to Engineering Courses

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Abstract

Many universities offer introductory engineering courses that can vary widely in content between institutions – even among sections within the same institution. The view into the underlying content in such courses is often obscured by the lack of a detailed syllabus and an incomplete description published in the University's catalog. Thus, assessment of a course sequence can be difficult due to the sheer volume of students and inconsistent content among sections. Moreover, the vagueness can affect transfer students, because awarding transfer credit implies a set of instructional objectives that the student may not have encountered. This project resulted in a classification scheme or taxonomy of topics commonly found in "Introduction to Engineering" courses. The taxonomy allows a mapping of potential course content to be achieved such that users can communicate their courses using a common tool. The investigators utilized a three-stage qualitative research design situated in the "purposes," "content," and "sequencing" constructs of Lattuca and Stark's model of an "Academic Plan." The first two stages involved a survey of 28 syllabi for "Introduction to Engineering" courses followed by culling topics from transcripts of 6 focus groups of 4 first-year instructors in a conference workshop using content analysis. A culminating three round Delphi study with 24 participants served to finalize the taxonomy. Course content centered around eight primary aspects that frame the taxonomy, each of which was broken down further to include more specific topics that might be found under them. Note that the taxonomy represents a list of topics that *may be* found in "Introduction to Engineering" (or similar) courses as opposed to a list of all topics that *should be* covered. Instructors can now use "The Introduction to Engineering Course Classification Scheme" as a tool to aid in communicating their courses by classifying it in terms of common course topics – a universal syllabus of sorts. Schools interested in alternative methods of awarding transfer credits or curriculum development for courses like "Introduction to Engineering" can be empowered to make decisions that are more informed using the taxonomy as a flexible artifact of their processes.

Keywords: first-year engineering, taxonomy, classification, introduction to engineering

1. Introduction

As students enter their first year of study toward a Bachelor's degree in an engineering discipline, their schedule typically includes the core classes of physics, chemistry, calculus, and an introductory course in engineering. A course named "Introduction to Engineering" or "Foundations of Engineering," as the title implies, intends to introduce a student to engineering; however, comparing courses of an identical or similar name, even at the level of course objectives, results in a high degree of variability in content. In fact, the high degree of variability may exist among sections of a course within a given program or institution. Different models of pedagogical development exacerbate the problem: instructors may design the course (or their section of the course) to meet objectives *they* feel to be most important, poorly representing the department's opinion.

While there is a proliferation of literature in the first year of study in engineering including recommendations of important and relevant content to include, the literature was devoid of a complete taxonomy – a classification scheme – defining issues which could be and/or should be found in these courses. After all, specifying topics that *could be* included within an introductory course is a prerequisite toward a specification of what *should be* in these courses.

This article describes the development of a taxonomy for first-year engineering courses. Multiple methods of data collection were employed, including a survey of syllabi available on the Internet and targeted focus groups at a national engineering education conference – analyzed using content analysis. A three-round Delphi procedure was used to achieve consensus on the taxonomy among survey participants for the classification scheme. The resulting scheme was then tested in the context of three focus group at conferences (First Year Engineering Experience 2013, American Society for Engineering Education North Central Conference 2014, and First Year Engineering Experience 2015) and implemented in institutions that used the taxonomy to investigate internal variability of first-year programs in the process of a first-year course redesign.

2. Literature Review

There is a wealth of research in the first year of engineering focusing on student success directly related to curricular design and coursework [1-5] including building a foundation in math [6]. Brannan and Wankat [7] examined multiple components of introductory courses in the first year of engineering. A key finding of the report was that the term "Introduction to Engineering" is inherently vague and can describe a superset of courses with fundamental differences in pedagogy, content, and course objectives. Limited research has been done to classify first-year engineering courses.

To account for such differences, mapping the terrain of first-year engineering through a taxonomy would prove to be valuable. A taxonomy as a tool is often employed in educational settings to provide instructors with a catalog of student learning objectives and the assessment of the outcomes. The development and use of taxonomies is prevalent in engineering education. Bloom's Taxonomy is perhaps the most well-known taxonomy in the field of education as it allows for the classification of different learning objectives into three domains: cognitive, affective, and psychomotor [8], or the 2001 revision classifying learning into 19 specific cognitive processes [9]. Assessing student learning in engineering often occurs through the lens of Bloom's Taxonomy, particularly when determining whether ABET outcomes have been met [10-14]. The famous taxonomy has also been employed beyond its originally intended use, such as determining the goals of students upon graduation in the context of engineering [15].

Many educational efforts base their ideology on the principles of Bloom's Taxonomy. For instance, Fuller and colleagues deemed the development of a computer science-specific learning taxonomy was necessary due to disagreement with the hierarchy of learning outcomes in computer science compared to Bloom's Taxonomy or other generic taxonomies on student learning [16]. Faculty in computer science have still attempted to apply Bloom's Taxonomy to form proper student-learning objectives, despite the development of a discipline specific taxonomy [17]. Like any tool, the taxonomy has limitations; Ferris and Aziz describe a psychomotor skills extension in their paper for the specific purpose of correcting deficiencies in Bloom's Taxonomy – much like computer science [18]. Other taxonomies have attempted to capture other skills such as conceptual and problem-solving competencies, such as the Concept and Problem Solving Inventory (CPI) [19].

An example of a taxonomy born within the context of the field of engineering education is the Taxonomy for Engineering Education Research [20, 21]. Due to the broad and rapidly evolving field of engineering education, Finelli and Borrego developed and refined a taxonomy with the intention of establishing a common nomenclature among professionals in the field, thereby making research results more accessible by specifying areas of interest to the community [20]. Practically speaking, this taxonomy answers the need to make sense of the landscape of engineering education. First-year engineering faces a similar dilemma, the continuing refinement of engineering programs in the beginning years makes describing the first-year experience particularly difficult. Perhaps the most relevant taxonomy available is called the Conceive-Design-Implement-Operate (CDIO) syllabus [22]. The CDIO syllabus is a list of topics that were developed for defining a list of knowledge, skills, and attitudes possessed by graduating engineers. While it is certainly an applicable taxonomy for the broad community of engineering educators, its scope reaches far beyond the first year in engineering and is not directly suitable to classify the first year of study due to its wide span of content.

The investigators deemed a classification scheme for introduction to engineering courses as a suitable solution. As a course that contributes to the first-year engineering experience, the knowledge or skills highlighted in such offerings should be captured alongside the outcomes of other traditional first-year courses such as Calculus and Physics.

3. Methods

The classification scheme was developed using a three-stage qualitative design. Accordingly, content analysis was applied on 28 course syllabi for "Introduction to Engineering" courses in the first stage followed by transcripts of 6 focus groups of 4 first-year instructors in a conference workshop (called Catalyzing Collaborative Conversations) in the second stage. The first two stages resulted in similar taxonomies. To synthesize and expand on the content analysis, a three round Delphi study with 24 participants was conducted to create a "final" taxonomy in the third stage. A preliminary round served to combine the previous two taxonomies while the second and third rounds were two reviews of the synthesis. The taxonomy was then tested at three conferences: First Year Engineering Experience 2013, American Society for Engineering Education North Central Conference 2014, and First Year Engineering Experience 2015. We err on the side of caution with the term "final," as the taxonomy will likely naturally evolve as the collective curriculum of first-year engineering changes to meet institutional, governmental, and societal needs; thus, the process of testing and dissemination is expected to be a continuous process. A graphic outlining the methods is depicted in Fig. 1. Continual refinement is emphasized in the testing and dissemination; each pair of arrows is a feedback loop, with the First Year Engineering Experience (FYEE) conference from 2013 as an example.

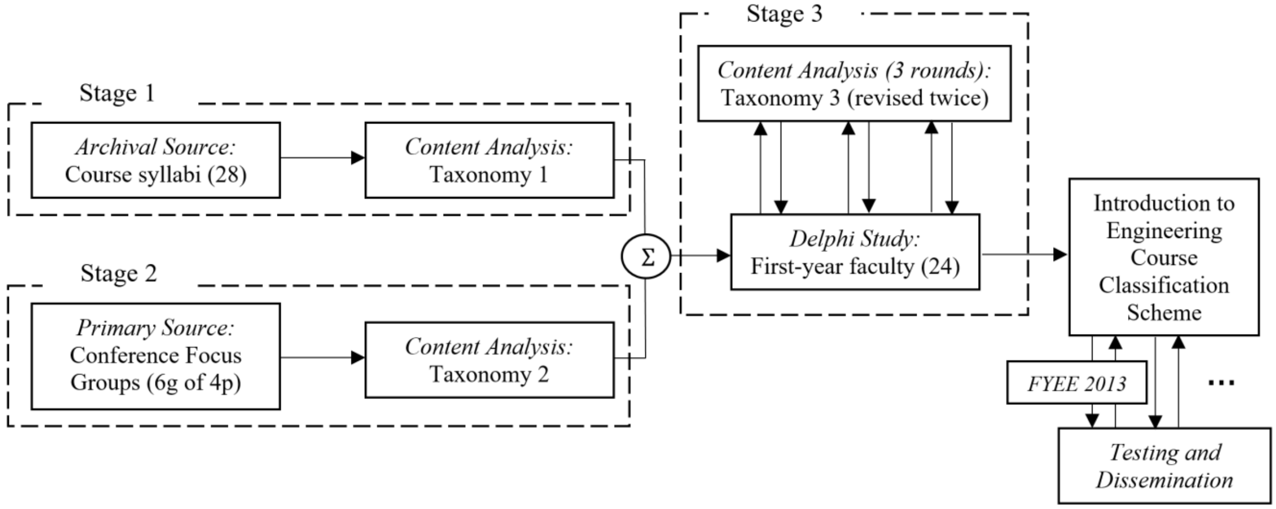


Figure 1: Diagram of Methods Implemented in Developing the Taxonomy

Note that "primary source" in this case refers to the fact the data was collected from a participant teaching an introductory course firsthand and does not imply priority.

3.1 Theoretical Framework

The study was situated in Lattuca and Stark's Model of Academic Plans in Context [23], which describes a curriculum at any level (a course, program, etc. – abstracted as an "academic plan") in terms of institutional-level and unit-level factors within the undergraduate curriculum: purposes, content, sequence, learners, instructional processes, instructional resources, evaluation, and adjustment. Grounded theory was used to construct the model, beginning with a content analysis of the literature related to curriculum organization and surveying actors in the educational system (faculty, students, and administrators) using a questionnaire [23, 24].

The model contains three layers: at the core is the *academic plan* – the curriculum – and the students navigating it. The curriculum sits within the *educational environment*, a product of both internal and external influences. Finally, the educational environment is placed within a *sociocultural context*. For our purposes, the area of interest is specifically within the academic plan itself. To study "Introduction to Engineering" courses, the content, course sequencing, and the purpose (of the course) are the important elements to consider. To this end, we seek to contextualize the variety in first-year engineering, particularly "Introduction to Engineering" courses, by extending Lattuca and Stark's model within the academic plan (Fig. 2) by resolving the following research questions:

- Research Question 1: What content is covered in introduction to engineering courses across the United States?
    - Research Question 1a: How is this content effectively represented to illustrate the relation between specific content?
    - Research Question 1b: How can this arrangement be used as a tool for engineering programs?

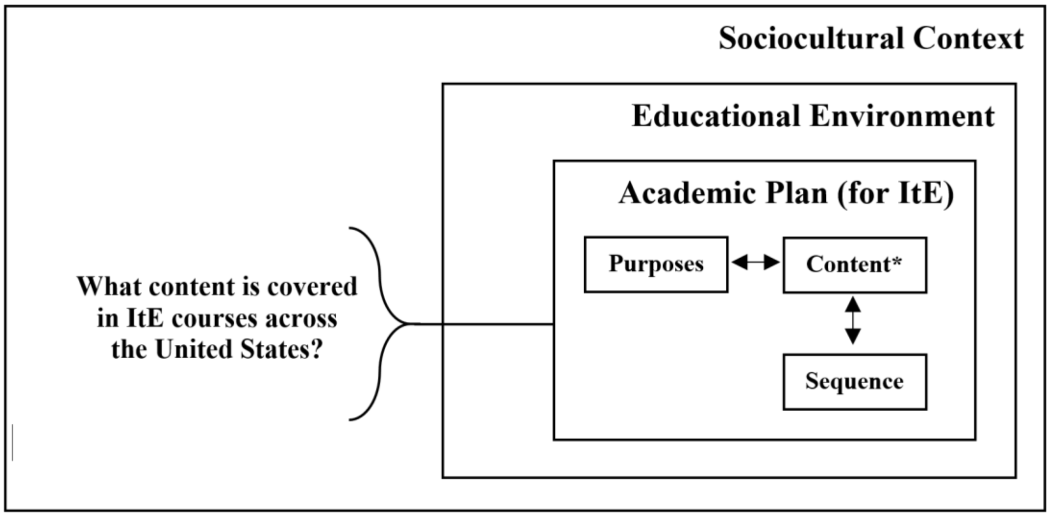


Figure 2: Extending the Model of an Academic Plan for Introduction to Engineering Courses (adapted from [23])

3.2 Stage 1: Survey of Syllabi

To identify common student learning objectives and course concepts from which topics may be implied, an Internet search of web sites from universities, colleges, and programs was conducted for courses with titles such as "Introduction to Engineering," "Engineering Fundamentals" or "Engineering 1." To be considered, a course needed to satisfy the following criteria:

- *Interdisciplinary:* The course must have been presented to an interdisciplinary population of first-year engineering students. "Introduction to Engineering" courses may contain technical content (such as MATLAB programming), but the course must be either intended for students in multiple disciplines or have an interdisciplinary focus to be included in the analysis. Courses such as "Introduction to Electrical Engineering" (i.e., a discipline specific course) were not considered for this round of data collection.
- *Not Orientation Specific:* Courses were not to be strictly focused on university orientation, even if a course had an engineering course designator, such as "ENG 100: Orientation". However, orientation may appear as a topic within an Introduction to Engineering course.
- *Not Extra-disciplinary:* Courses meant to introduce engineering to non-engineering majors were not considered. The intended student population within the course was to be exclusively engineering students.

The search was conducted by a team of two undergraduate research assistants who were majoring in Engineering Education during the spring 2012 semester. Researchers used common search engines to search to pinpoint key words associated with first-year engineering such as "introduction to engineering." When a course meeting the three criteria was found online, the team of undergraduate research assistants would attempt to locate a relevant course syllabus. Each syllabus was then checked against the three criteria to exclude any course outside the scope of this study.

Through the internet search, the team identified 28 syllabi that were available meeting the criteria as specified. Each undergraduate research assistant was assigned to review 14 syllabi to ensure that each syllabus received two reviews as a form of member checking [25]. Each course topic specified in the syllabus was cataloged by the reviewers. Since the intent of the data collection phase was to capture an exhaustive list of topics, the team also reviewed available assignments and course descriptions to capture any other topics that may have been implied, but not specifically listed in the syllabi.

To initially categorize the topics extracted from the online syllabi, the team developed a concept map by grouping similar topics using post-it notes on a whiteboard. If topics were closely related, group consensus was reached to determine whether the topics were fundamentally identical; in these cases, one of the identical topics would be dropped from consideration with an effort to retain the most descriptive of the two.

As the initial concept map was developed and topics were arranged, the research team came to consensus on the heirarchical arrangement of all the topics.

3.3 Stage 2: Catalyzing Collaborative Conversations workshop

A workshop facilitating a gathering of faculty and administrators with a self-identified, inherent interest in first-year engineering took place at the Frontiers in Education (FIE) conference in Seattle, WA in October 2012. A Catalyzing Collaborative Conversations session was designed and organized jointly by Directors of First Year Engineering programs at Ohio Northern University and Virginia Tech. The special session at the conference offered the community an opportunity to come together and discuss existing and desired course outcomes and topics for introductory engineering courses as a group. The intent of the workshop was to build a second preliminary classification scheme to inform the final Delphi study. The guided, informal discussion enabled the participants to speak about their ideas freely such that the collective ideas of the group steered conversation toward the development or discovery of other ideas.

The 24 attendees were seated in groups of 6, and each group was tasked with having a discussion around a set of guiding questions distributed at the beginning of the workshop. To document important points of the conversation, each group appointed a recorder.

Guiding questions were prepared and distributed to each group. The complete set of conversation questions included:

- What are the objectives of first-year engineering programs?
- Why is there not a common set of objectives for first-year engineering courses?
- What would we consider the best practices for first-year engineering programs?
  For example, should we teach MATLAB/Excel rather than introducing students to the disciplines of engineering?
- If students were so successful in High School, why is there so much emphasis on success?
  What do we mean by success?
- Are there any objectives that are hard to assess? How might we assess them?
  Is there anything that we think should be a best practice that isn't because it is too difficult to assess?

The analysis focused on the answers to the initial question in the Catalyzing Collaborative Conversations workshop: "What are the objectives of the first-year engineering programs." The original intent was to allow each group a fixed amount of time for small group discussion then convene as a full group and have groups report out to the general audience; however, the conversations were judged to be valuable. Therefore, the leaders opted to allow the conversations to continue until the end of the session.

Results were collected from the recorder of each group and analyzed by the team of researchers. Members of the research team reviewed the set of 18 pages of notes from the reporters from each small group. Specific topics were recorded and any that were implied in other sections or within narratives were culled. Individual topics were grouped to form main factors and subfactors as before. Again, specific topics that may best fit in more than one subcategory were assigned to one of the appropriate subcategories rather than creating a new category since the goal was to capture all of the topics mentioned within the group and create a rough taxonomy. Using the same mind-mapping process from examining syllabi, a concept map incorporating the written comments of the reporters from each group was developed. The research team came to group consensus on any topics judged to be similar or identical and opted for the most descriptive of the two.

3.4 Stage 3: Delphi Study

The Delphi procedure encourages a group of participants with a common interest to develop shared images based on three rounds of question development and information with iterative feedback [26-29]. The Delphi procedure involved asking individuals for their list of topics independent of other participants around some idea. A draft list of topics is prepared, and a second round of questions asks participants for their critical analysis on the proposed list. Participant input is received, and a third round is conducted that is essentially a repeat of the second round. Typically, group consensus is reached after three rounds [26, 27].

The Delphi procedure was administered online to capitalize on an inherent advantage in this method, namely the elimination of 'groupthink,' where participants fail to fully participate or modify their responses based on the perceived majority opinions found in a group. This was likely to have occured during the Catalyzing Collaborative Conversations workshop held at the Frontiers in Education conference in Seattle, WA in October 2012 given the structure of the groups and format of the discussion.

Delphi studies can generate large quantities of information from each round; beyond a sample of approximately 35 participants, submissions tend to result in duplicate information [26, 29]. Therefore, an upper bound of 35 participants was sought.

Initial invitations to participate in the Dephi study orignated from a list generated by a steering committee of faculty in first-year engineering programs. E-mail invitations were sent to the listserv of the First Year Program Division of ASEE, all participants in the 2012 FYEE conference, and to a variety of universities with first-year engineering programs identified through ASEE and recent literature. Thirty-seven participants responded to the invitation indicating interest and 31 of the initial respondents completed the first round of data collection.

The structure of the first round of the Delphi study consisted of an instruction block containing four open-ended questions (Fig. 3).

While answering the following questions, please answer them within the framework of Introduction to Engineering / First-Year Engineering course(s). Do not consider other required courses within the first year.

For example, please do not consider math, science, or general education courses.

There are no right or wrong answers, and no specific number of items you must include. Please be as complete and descriptive as necessary to fully answer each question.

What topics are included (please list) in first-year engineering courses at your institution?

Are there topics that are not, but *should* be, included in first-year engineering courses at your institution? Please list. *(please do not duplicate answers from the previous question)*

What are (please list) the **expected student outcomes** in first-year engineering courses at your institution?

What other student outcomes *should be* included in first-year engineering courses? Please list. *(please do not duplicate answers from the previous question)*

Figure 3: Survey screen from first round of Delphi study

Since the intent of the Delphi survey was to collect as many topics as possible, it was not important to distinguish between topics already found in a course and those that were deemed as important to include in a course; questions seeking input on both existing and desired topics were posed to encourage participants to consider a full range of topics. Each answer was culled to identify objectives and topics. Results of the first two data collections were included at this point and objectives were added to those identified through the initial round of the Delphi procedure. A draft concept map was generated by grouping related topics, eliminating duplications from the synthesis (judged by a consensus among the research team), and specifying the relationship among the topics as before.

The second round included asking each participant to critically review the first draft of the scheme created from responses to the first round and the first two preliminary schemes to ensure that all topics were accurately represented. Participants were directed to a website with the scheme available for review, then to a survey site to record their responses. The following two open-ended questions were posed:

- After reviewing the proposed classification scheme / concept map, are all course outcomes in your existing course AND all outcomes that should be in an Introduction to Engineering course included in the diagram?
  If not, please list any that are missing.
- After reviewing the proposed classification scheme / concept map, are there any outcomes / topics / items that should be moved?
  Please describe which should be moved, where they should go, and briefly why.

Feedback from round two served to develop a "final" proposed classification scheme.

In the third round, participants received the "final" proposed classification scheme generated based on all prior work (online syllabi, conference workshop, Delphi study rounds 1 and 2), and were asked to use the scheme to analyze their courses, and provide any constructive criticism to refine the scheme. Specifically, participants were asked the following questions after using the scheme to analyze their courses:

- After classifying your Introduction to Engineering course, did the scheme classify your course as you expected?
- After classifying your Introduction to Engineering course, are all course outcomes in your existing course AND all outcomes that should be in an Introduction to Engineering course included in the diagram?
  If not, please list any that are missing.
- After classifying your Introduction to Engineering course, are there any outcomes / topics / items that should be moved?
  Please describe which should be moved, where they should go, and briefly why.

Using this updated classification scheme, the participants offered their final comments before the new version was tested at workshops held during the FYEE Conference in Pittsburgh, Pennsylvania in August 2013, the American Society for Engineering Education North Central Conference in Rochester, Michigan in April 2014, and FYEE Conference in Roanoke, Virginia in August 2015. Refinements based on feedback from the three test sites were included as appropriate.

4. Results

As in the methods, the results will be presented for each stage of the research design, then the final product and its use will be described.

4.1 Stage 1: Survey of Syllabi

The preliminary concept map from the evaluation of online syllabi and associated content resulted in a taxonomy that contained four primary upper levels based upon the frequency in which the topic was mentioned in the syllabi: Professional Skills, Engineering Skills, Orientation to the Profession and Orientation to the University / Program. Remaining topics were grouped and arranged based on the frequently of appearabce of each topic. The classification of the course objectives found in the examined syllabi is shown in Fig. 4.

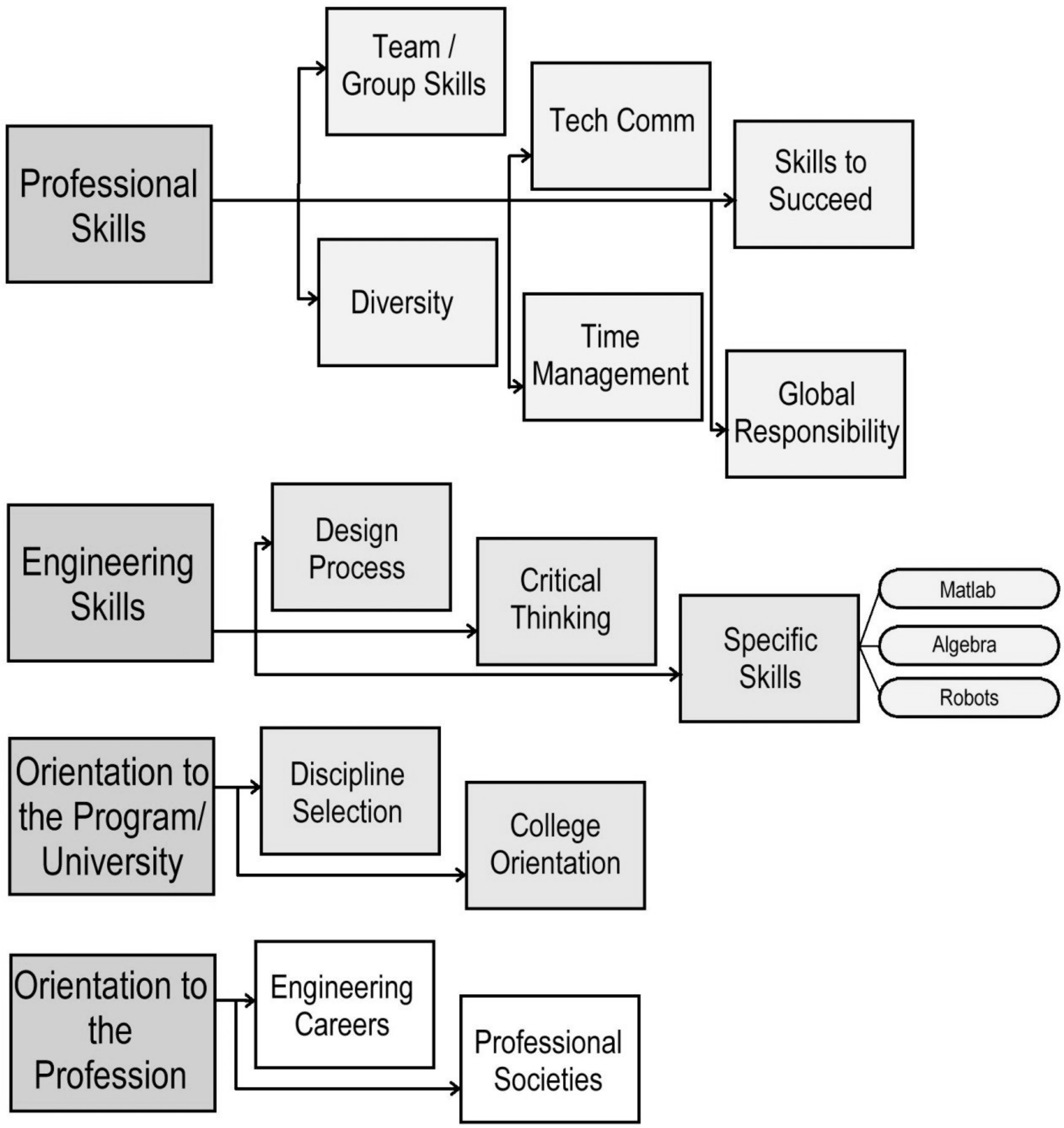


Figure 4: Classification Scheme Developed Through the Use of Online Syllabi

In Fig. 4, the scheme is shown down to a subfactor level; in other words, "Team / Group Skills" is a comprehensive topic which includes the various aspects of teamwork and communication. Since the goal of surveying the syllabi was to form a draft of a taxonomy to inform the final scheme, there was limited effort to further refine more granular topics. As one may expect, it is difficult to achieve a clear delineation of topics; in other words, a topic mentioned in an arbitrary syllabus may fit under two different categories as defined in this first version of the classification scheme.

Unlike the "final" version of the classification scheme, the physical order in which the subcategories appear is meaningful; at any level, topics appearing more often in syllabi appear first (on the left) and decsend toward the right as the prevelance of topics begins to wane. To provide an example, 'teaming / group skills' appears at the far left since it was mentioned the most, while 'global concerns' is on the far right since it was mentioned less frequently.

4.2 Stage 2: Catalyzing Collaborative Conversations workshop

The first question posed to each group, "what are the objectives of first-year engineering programs?" generated most of the conversation by far, and most comments were listed under this item in the notes from each recorder. When a group addressed other questions, the discussion typically drifted back to the first question or became a conversation concerning objectives that should ideally be, but may not currently be, included – all of which contribute to the goal of the data collection in this case.

Fig. 5 presents the concept map of topics generated by notes from the group discussions. As topics were classified, it became clear that they would be classified into similar themes as in the analysis of syllabi.

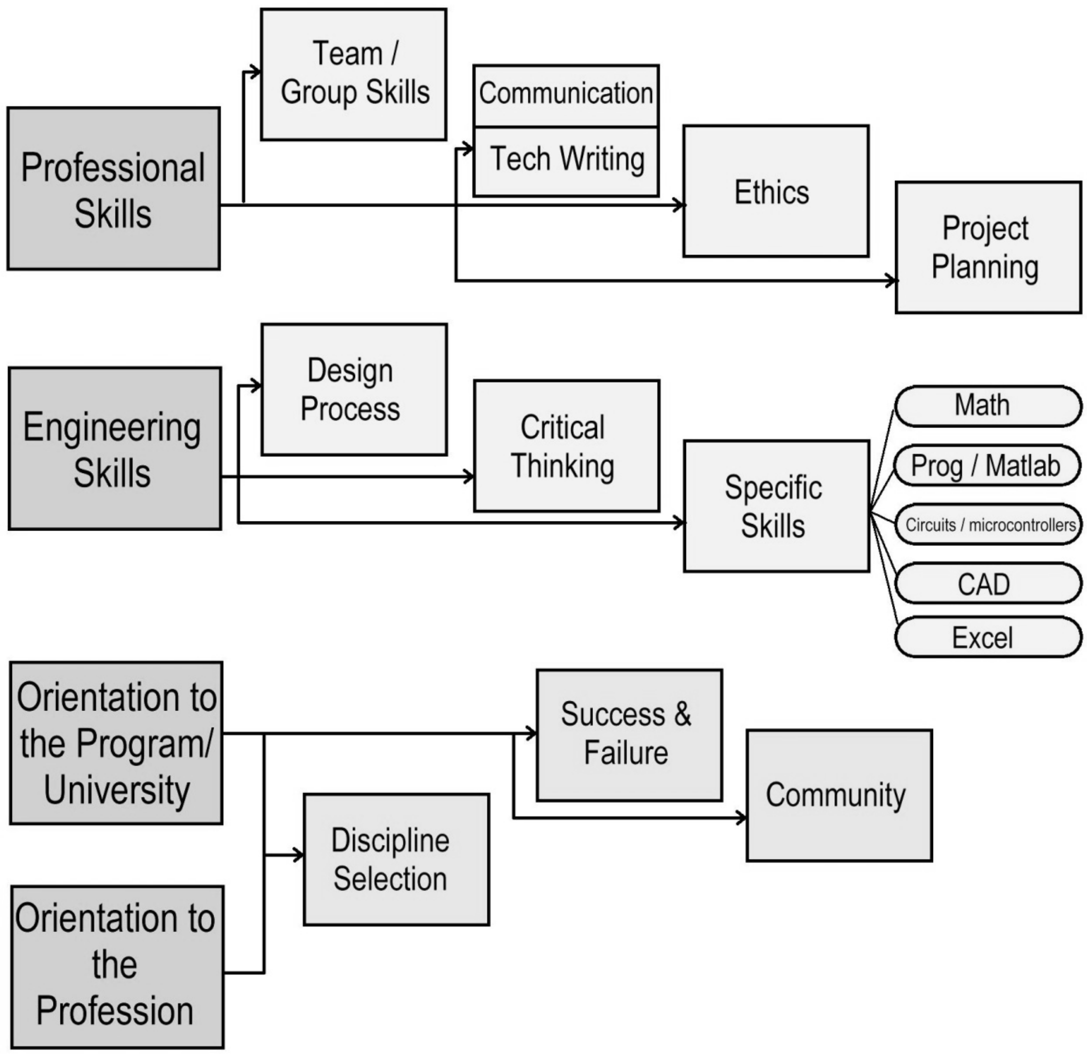


Figure 5: Classification Scheme Developed Through the Results of the CCC Workshop

Items are categorized by the frequency in which they were mentioned in the notes; here, left comprises the high frequency items. Each item listed in Fig. 5 was mentioned more than once. An exception is made for specific technical or discipline specific engineering skills; in these cases, each technical topic was captured. These were included for the sake of comparison.

4.3 Stage 3: Delphi Study

As anticipated, the open-ended nature of the initial round of Delphi questions along with the inclusion of topics that "should be, but are not included" led to a more complete picture of all possible topics included in "Introduction to Engineering" courses. Individual topics were sorted into nine main categories: communication, design, latent curriculum / professional skills, engineering profession, academic advising, math skills and application, engineering specific technology, grand challenges, and pedagogy. Eight of these nine highest-level categories map directly to the four main categories from the prior two analyses.

Pedagogy became the subject of debate in the second round of the Delphi process. Participants argued that "pedagogy" did not align with the intent of classifying course *topics*, as pedagogical methods utilized in a course are certainly not equivalent to course topics; accordingly, "pedagogy" was eliminated from the scheme. This completed the initial version of the taxonomy.

The workshop conducted at the 2013 FYEE primarily focused on participants completing the scheme for their course(s). This allowed the scheme to be tested with authentic data as well as obtaining data from sample courses that were completely classified. Participants classified 28 unique courses from 24 institutions. With the sample of 28 courses, preliminary attempts were made to connect a course's list of classified topics with the primary focus of the class in comparison with other universities [30]. The remaining two testing sites only contributed small alterations such as more complete descriptions of a certain topic and corrections to errors in labeling.

4.4 The Taxonomy

The methods as described resulted in three iterations of what was termed the *Introduction to Engineering Course Classification Scheme*. Content within first year engineering was found to be described in terms of eight prevailing categories called main topics. The eight main topics are: Communication (COMM), Engineering Profession (ENPR), Math Skills and Applications (MATH), Design (DESN), Global Interest (GLIN), Latent Curriculum / Professional Skills (PROF), Academic Success (ACAD), and Engineering Specific Technology/Tools (ESTT). The top level of the taxonomy is composed of the main topics, shown in Fig. 6. Descriptions of each main topic and their relevance to the first year are provided in Table 1.

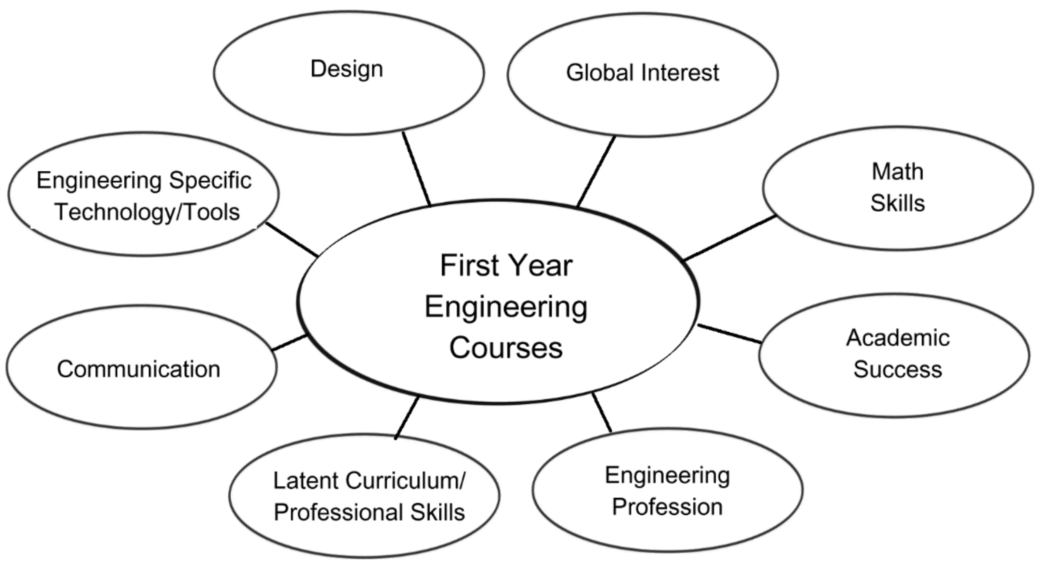


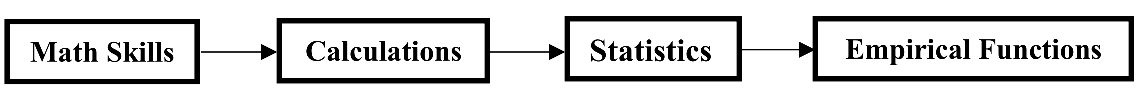
Figure 6: Top Level of the Classification Scheme [30]

Table 1: Descriptions of Main Topics in the Taxonomy as they Relate to Introduction to Engineering Courses

Main Topic	Description
Academic Success (ACAD)	For students to be successful, first-year engineers are given the resources to excel and progress in their academic career.
Communication (COMM)	To be a working professional, students are given the proper instruction for communicating effectively through all channels.
Design (DESN)	To understand the engineer's process, students are instructed in the fundamentals of design and methods to reach a desired goal for a project.
Engineering Profession (ENPR)	Students must understand the professional aspect of being an engineer and are instructed on topics such as the engineering disciplines, their roles and responsibilities, and the history of the profession.
Engineering Specific Technology / Tools (ESTT)	Students must be technically proficient to be a well-rounded engineer; this includes skills like programming and computer aided drafting.
Global Interest (GLIN)	To be ready for the future, students must be aware of the challenges proposed by the National Academy of Engineers to improve life as we know it.
Math Skills and Application (MATH)	Students must have a strong foundation in mathematics to be able to perform the necessary calculations later in their studies and as an engineer.
Latent Curriculum / Professional Skills (PROF)	Students will rarely be working alone; therefore, they must develop interpersonal and intrapersonal skills.

4.4.1 Classification of Topics

Below the top level, the taxonomy is further divided to accommodate more specific content. The main topics are denoted by four-letter codes. A topic indexed under a main topic is assigned a Roman numeral. Further, sub-topics that are indexed under a topic are given a letter. Topics that are then indexed under sub-topics are called specific topics - these are given a number [31, 32]. This relationship is shown in Fig. 7. The arrows indicate progression deeper into the more specific topics in the taxonomy.



Level	Main Topic	Topic	Sub-Topic	Specific Topic
Code	Four Letter Code	Roman Numeral	Letter	Number
Example	MATH	IX.	A.	1.

General ---> *Specific*

Figure 7: Specifying a Topic Using the Scheme

To best convey this ordering system, the appropriate label to one specific topic from the taxonomy is shown, "Empirical Functions." "Empirical functions" is indexed under Statistics, which is under Calculations, then indexed under Math Skills as shown. Thus, it is denoted as follows: Main Topic MATH, Topic IX, Sub-Topic A, Specific Topic 1.

In short, the classification method simplifies this topic's ID to MATH IX.A.1. If no sub-topics or specific topics are indexed under the topic, then a zero is used as a placeholder to preserve structure. An example of this case would be "Types of Engineering," which is topic IV indexed under Engineering Profession. Since "Types of Engineering" has no sub-topics or specific topics, it is given the code ENPR.IV.0.0 [31, 32].

Explicit connections between topics were identified during the development of the taxonomy. To signify this special condition, the ID was given a superscript, which directs the user to more information about the connection. The topic itself is then referred to as a *tied topic*. In most cases, the tied topics are merely suggested relationships to encourage the accurate classification of a first-year engineering course [31, 32].

In addition to the taxonomy, check sheets listing all the identified topics are included. The process of completing these check sheets is referred to as "classifying a course." To classify a course, the user 'checks' each topic that is covered in the course, leaving those that are not covered unchecked. The overall group of checked topics represents the completed scheme for a given class (or section). The taxonomy was developed with the intention for courses to be classified individually, but programs with multiple courses comprising the first year of engineering can combine results and view the results holistically.

The classification scheme was used during a National Science Foundation sponsored workshop at the FYEE Conference in 2013 [30]. Samples from 28 different classified courses were collected and analyzed [30]. The investigators were primarily interested in feedback that could assist in refinement. As a result, minor edits were made to the taxonomy. With consideration of the edits, the taxonomy is shown in Fig. 8 with a visual representation of each main topic cluster in Figs. 9 through 16 which connect to form a graphical map of Fig. 8. The completed scheme illustrates the overall suite of possible topics found in these courses as well as the relation between topics.

Communication (COMM)

- *I. Professional*
  - *A. Client Interactions*
- *II. Written*
  - *A. Reports*
    - *1. Lab*
    - *2. Documentation*
    - *3. Engineering*
  - *B. Email Writing*
  - *C. Résumé*
- *III. Oral and Visual*
  - ***A. Presentations (COMM IV.A.0 / ESTT II.D.3)***
- ***IV. Visual (ACAD III.0.0 / COMM III.A.0)***
  - *A. Posters*

Engineering Profession (ENPR)

- *I. Relevance of the Profession*
- *II. Images of Engineering in Today's Society*
  - *A. Roles and Responsibility*
- *III. Professional Societies*
  - ***A. Student Organizations (PROF VI.0.0)***
- *IV. Types of Engineering*
- *V. Engineering History*
- *VI. Definition and Vocabulary*
  - *A. Nature of Engineering*
  - *B. Nature of Technology*
- *VII. Disciplines of Engineering*
  - *A. Intro to Professions*
- ***VIII. Commitment to Discipline (ACAD VII.0.0)***

Professional Skills (PROF)

- *I. Critical Thinking*
  - ***A. Problem Solving (DESN III.0.0)***
- ***II. Ethics (ACAD IV.0.0)***
  - *B. Codes and Standards*
- ***III. Teamwork (DESN V.F.2)***
  - *C. Team Management*
    - *1. Work Distribution*
    - *2. Strength / Weakness ID*
  - *D. Team Dynamics*
- *IV. Research*
  - *E. Library Resources*
  - *F. Quantitative*
  - *G. Qualitative*
- *V. Patent Search*
- ***VI. Leadership (DESN V.A.0 / ENPR III.A.0)***
- *VII. Entrepreneurship*

Design (DESN)

- *I. Engineering Analysis*
  - *A. Data Collection and Statistical Analysis*
- ***II. Problem Solving (PROF I.A.0)***
  - *A. Problem Formulation*
- *III. Criteria and Constraints*
  - *A. Design Trade-offs*
- *IV. Project Management*
  - ***A. Documentation and Management (PROF VI.0.0 / COM II.A.2)***
  - ***B. Scheduling(ACAD II.A.0)***
  - *C. Verification*
  - *D. Quality Control*
  - *E. Data Management*
- *V. Engineering Design*
  - ***A. Fundamentals of Design (DESN I.F.3)***
    - *1. Mathematical Modeling*
    - *2. Physical Modeling*
    - *3. Formal Design Process*
    - *4. Brainstorming*
    - *5. Concept Selection*
    - *6. Testing Hypothesis*
    - *7. Design Review*
    - *8. Refine*
  - *B. Reverse Engineering*
  - ***C. Research (PROF IV.0.0)***
    - *1. User testing*
  - *D. Creativity and Curiosity*
  - *E. Empirical Design*
  - *F. Authentic Design*
    - *1. Engineering Feats and Failures*
    - ***2. Design Projects (PROF III.0.0)***
    - ***3. Realistic Design (DESN I.A.0)***

Math Skills (MATH)

- *I. Trig Review*
- *II. Calculus*
- *III. Significant Figures*
- *IV. Units and Dimensions*
- *V. Dimensional Analysis*
- *VI. Linear Regression*
- *VII. Matrices*
- *VIII. Abstraction*
- *IX. Calculations*
  - *A. Statistics*
    - *1. Empirical Functions*
  - *B. Graphing*
  - *C. Estimation*

Global Interest (GLIN)

- ***I. Grand Challenges (DESN I.F.0)***
- *II. Concern for Society*
  - *A. Assistive Technologies*
  - *B. Social Entrepreneurship*
  - *C. Design Safety*
  - *D. Sustainability*
- *III. Biomechanics*
- *IV. Bioinformatics*
- *V. Virtual Reality*
- *VI. Geotechnical Engineering*

Academic Success (ACAD)

- *I. Community*
  - *A. Relationships and Friendships*
- *II. Personal Management*
  - ***A. Time Management (DESN V.B.0)***
  - *B. Stress Management*
- ***III. E-Portfolio Design (COMM II.C.0)***
- ***IV. Academic Integrity (PROF II.0.0)***
- *V. Advising*
  - *A. Plan of Study*
  - *B. Study Abroad*
  - *C. Co-op or Internship*
    - *1. Interviews*
  - *D. Intro to Campus*
  - *E. Intro to Departments*
  - *F. Undergraduate Research*
- *VI. Lifelong Learning*
- ***VII. Commitment to Discipline (ENPR VIII.0.0)***

ENGR Specific Tech/Tools (ESTT)

- *I. Engineering Skills*
  - *A. Electromagnetic Systems*
  - *B. Circuits*
  - *C. Statics*
  - *D. Mechanics*
  - *E. 3-D Visualization*
  - *F. Material Balance*
  - *G. Thermodynamics*
  - *H. Sketching*
- *II. Software*
  - *A. Programming**
  - *B. Programming and Design**
  - *C. Computer Aided Design**
  - *D. Microsoft Office**
- *III. Hardware*
  - *A. Shop Experience**
  - *B. Topic Specific Tools*
    - *1. Bread boarding*
    - *2. Arduino Based Project*
    - *3. Basic Surveying*
    - *4. Laboratory*
    - *5. Nanosensors*

**Topics indexed under this sub-topic were omitted to conserve space. Please review the complete version of the scheme for the expanded list.*

Note: A labeled topic in **bold** designates that it and one or more topics were identified as related during development. The classification scheme defines the non-trivial relationship between the topics so the user understands what would constitute an appropriate marking.

Figure 8: All Topics within the Complete Classification Scheme

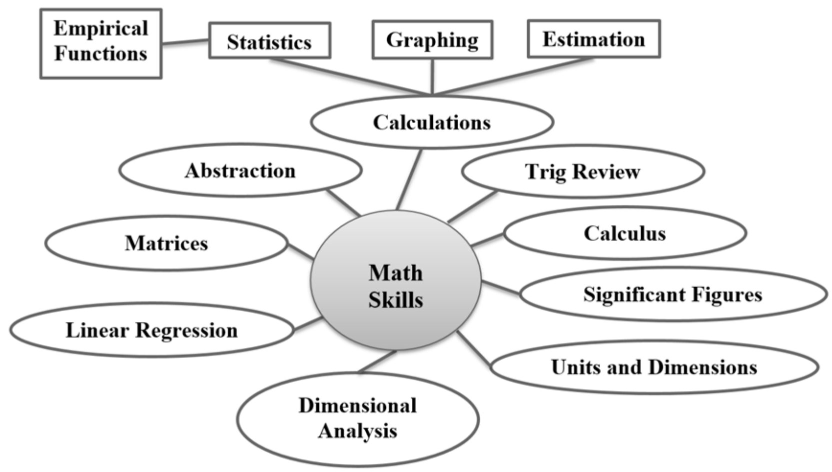


Figure 9: Math Skills Topic Cluster

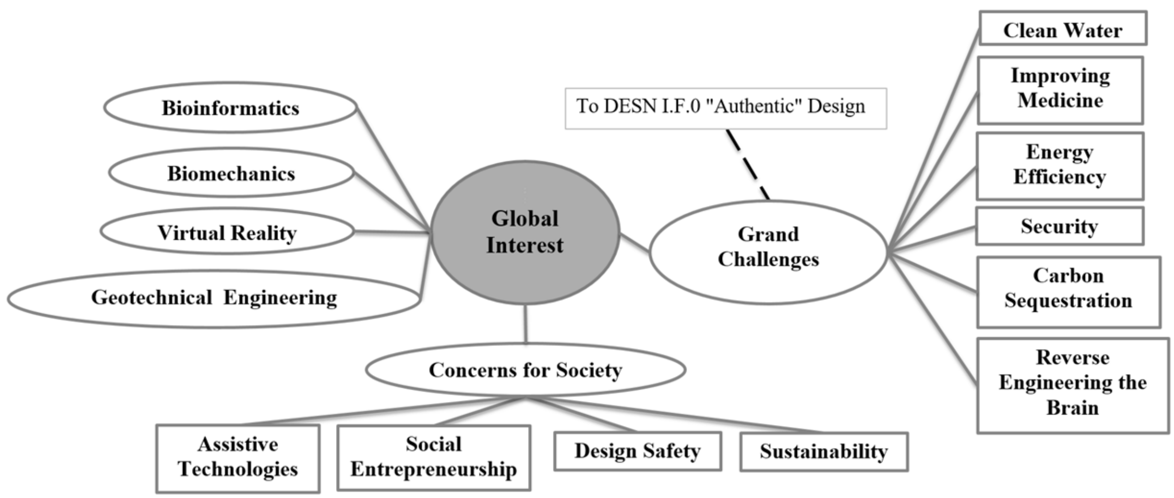


Figure 10: Global Interest Topic Cluster

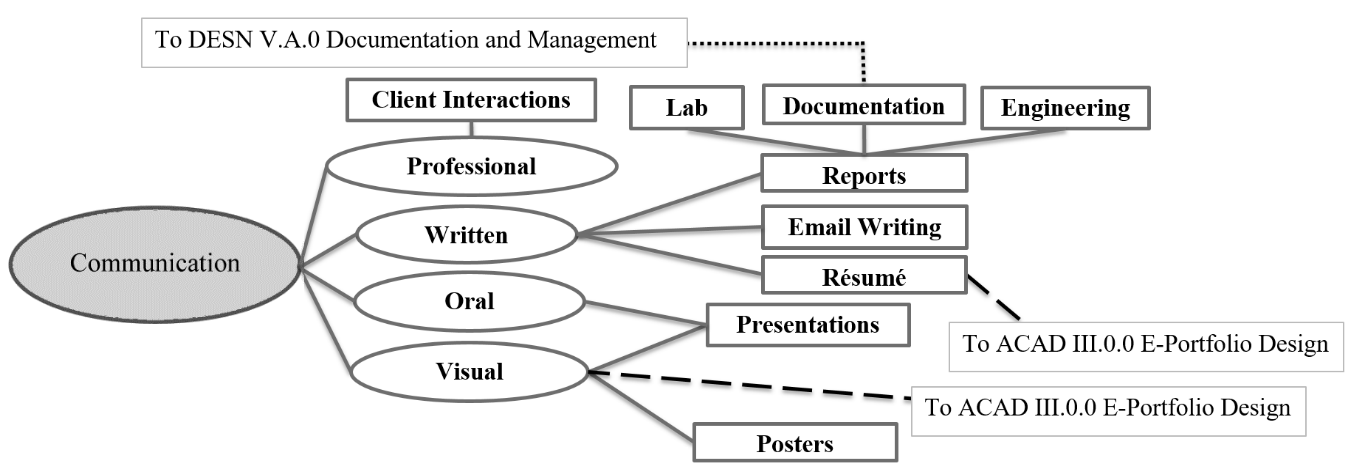


Figure 11: Communication Topic Cluster

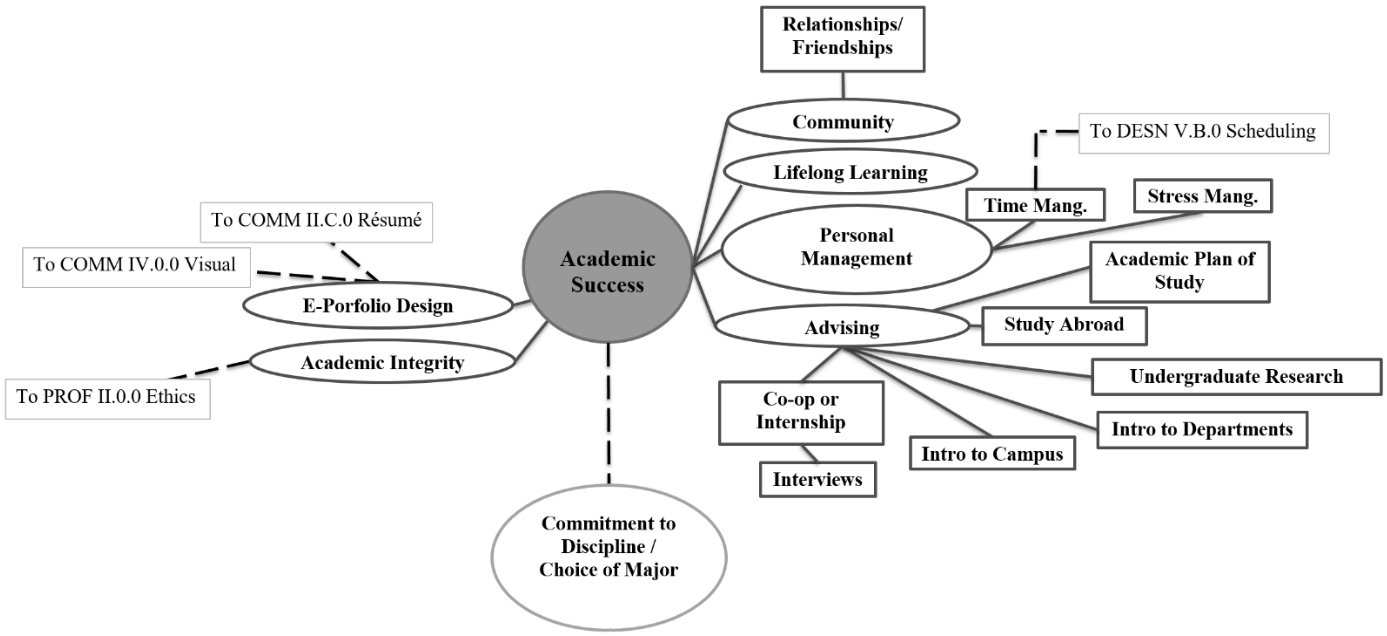


Figure 12: Academic Success Topic Cluster

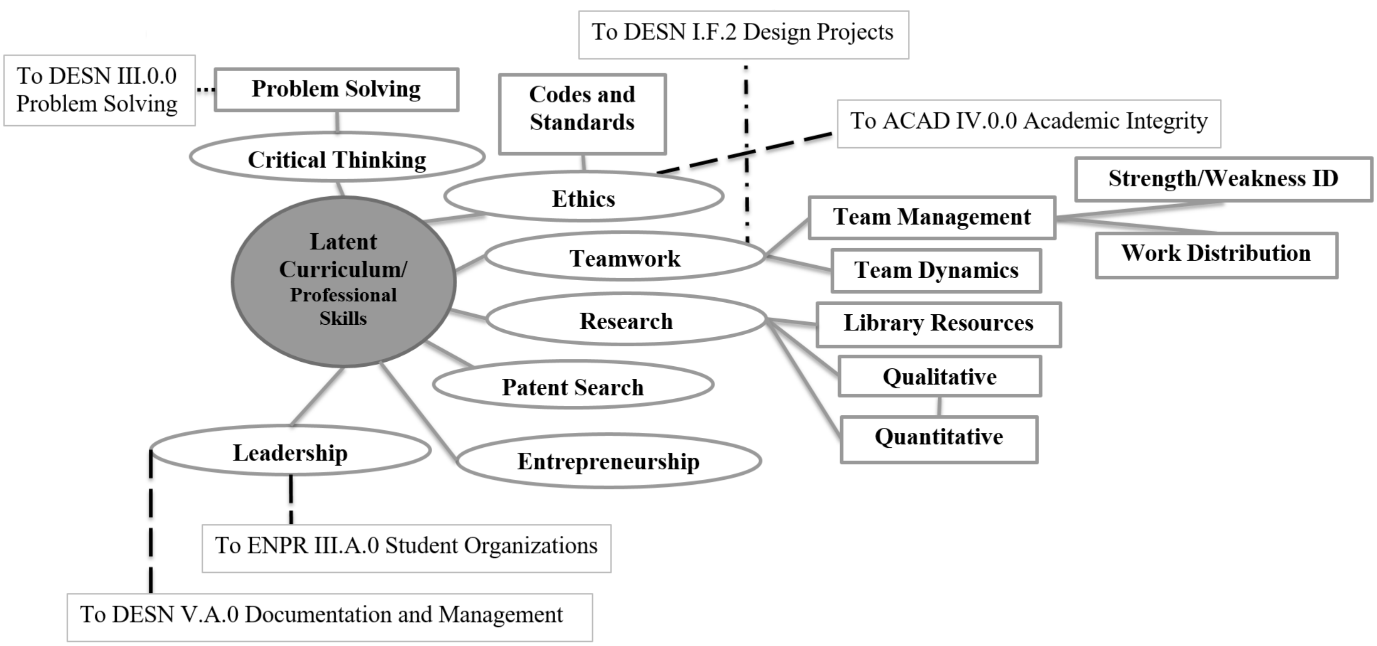


Figure 13: Latent Curriculum / Profession Skills Topic Cluster

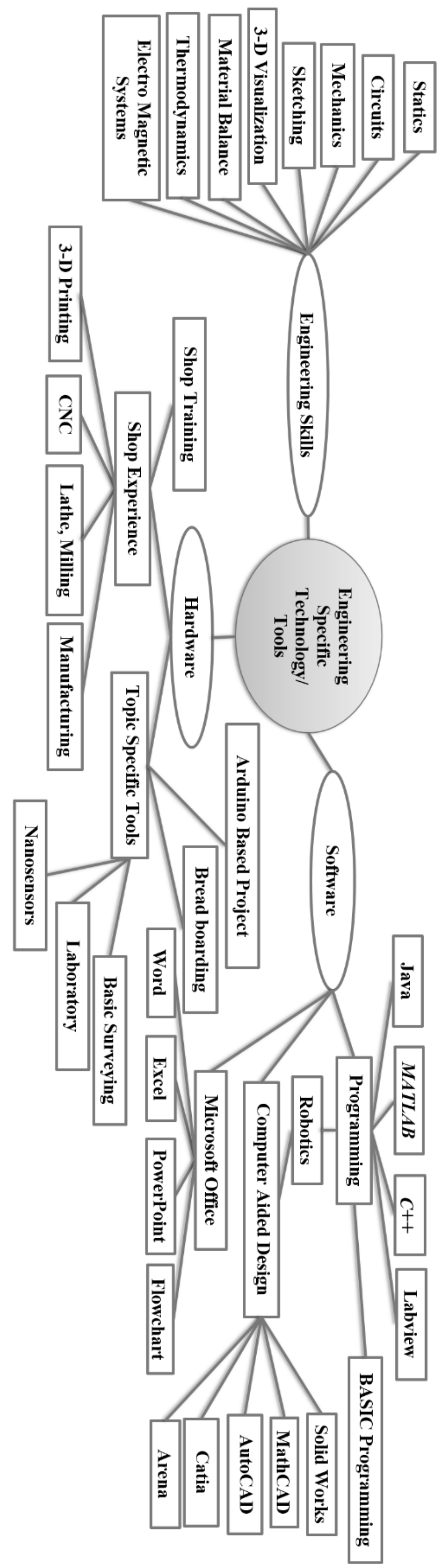


Figure 14: Engineering Specific Technology / Tools Topic Cluster

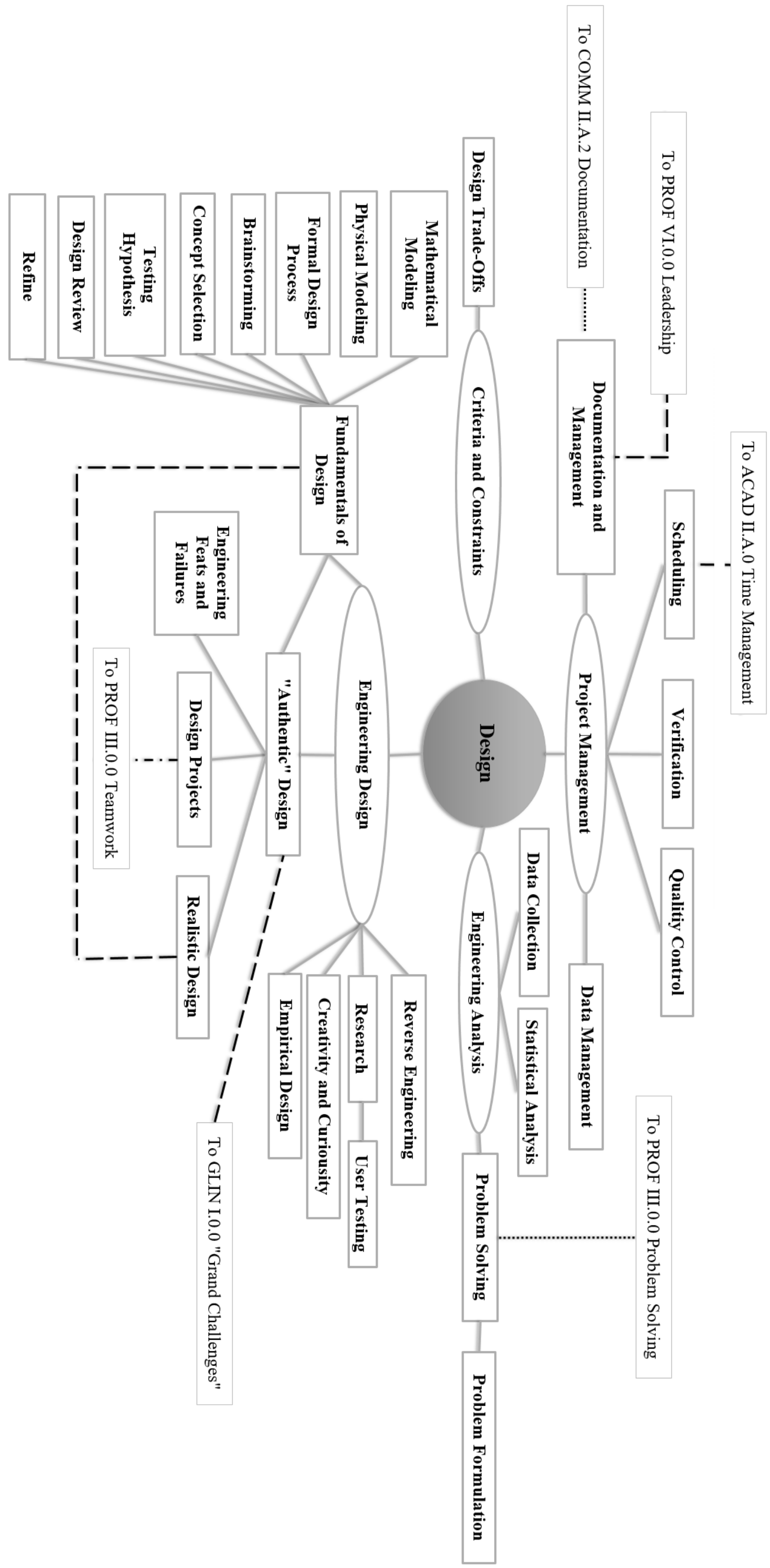


Figure 15: Design Topic Cluster

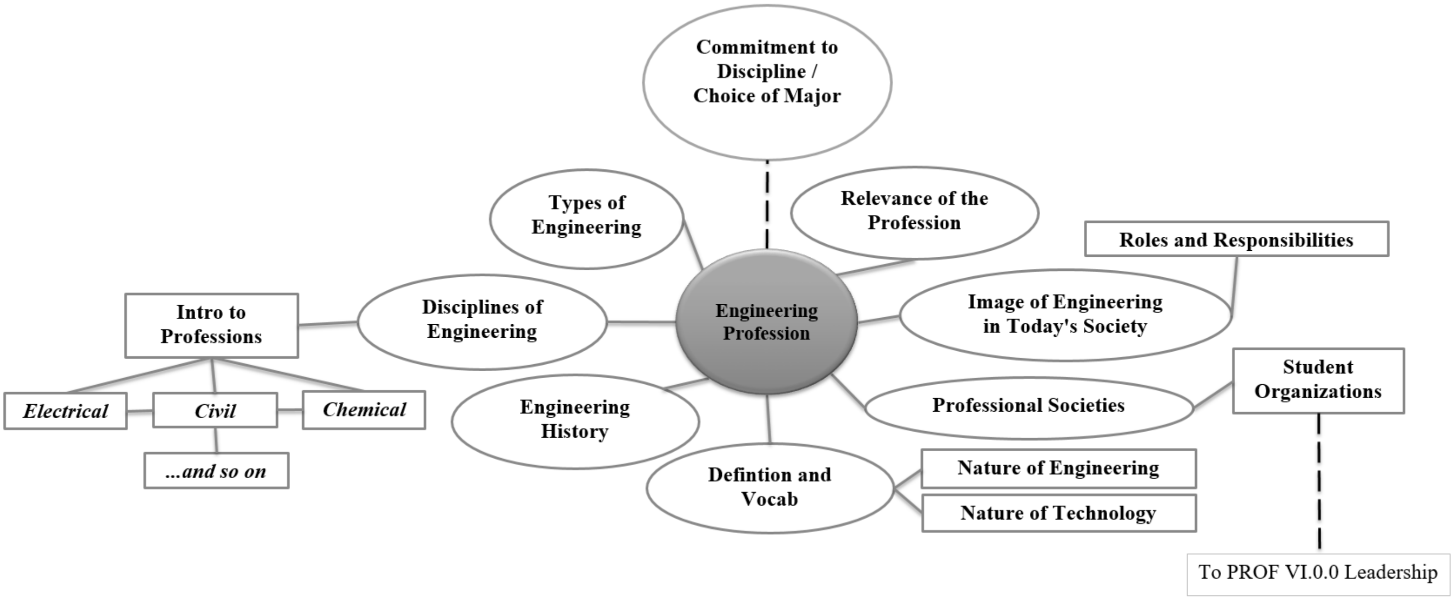


Figure 16: Engineering Profession Topic Cluster

5. Discussion

Through the incremental development of the scheme, a few differences were noted between the preliminary taxonomies. Recall from Figures 4 and 5 that topics emerged into 4 overarching themes: Professional Skills, Engineering Skills, Orientation to the Program / University, and Orientation to the Profession.

5.1 Engineering Skills

The specific topics and skills under the Engineering Skills category showed the least difference between the two methodologies. The group discussion at the workshop generated more content in the engineering skills category than the analysis of the syllabi [32, 33]. This is perhaps attributed to the dynamics of the group discussion and a lack of specific technical skills explicitly listed in the course syllabi. The Delphi study, which resulted in the finalized classification scheme, greatly expanded on this idea of Engineering Skills. The result was a much more expansive listing and categorization of discipline specific skills that were distributed under more appropriate headings – such as moving "Calculus" to "Math Skills."

5.2 Professional Skills

In the case of Professional Skills, competencies associated with teaming and communication were mentioned frequently in both group discussion and syllabi [32]. Since these characteristics are specifically mentioned in ABET standards and from various employers as desirable outcomes, it is not surprising that these skills are prevalent. Engineering ethics and project planning did not appear in the analysis of syllabi examined in the first stage of development, but were often mentioned during the CCC workshop as higher priority objectives. It is unclear why these two topics were not explicitly mentioned in course syllabi.

A distinction between the different types of communication emerged during the CCC workshop. The more generic objective, "Communication," was introduced during the analysis of the syllabi; however, the CCC workshop provided the motivation to delineate different modes of communication: technical, visual, and verbal. This distinction was captured in the final version of the scheme under the heading of "Communication."

Like Engineering Skills, Professional Skills and its associated topics were incorporated into more suitable categories: "Latent Curriculum/Professional Skills" and "Engineering Profession."

5.3 Orientation

As a result of the Catalyzing Collaborative Conversations discussion, “orientation” was split into two specific categories: “orientation to the program” and “orientation to the disciplines and the profession”. In a similar vein of ethics and project management, orientation only appeared specifically as a course objective in one syllabus [31, 32]. The Delphi study broadened this category as topics associated with advising, personal management, and community emerged. Thus, orientation topics were absorbed under the heading, “Academic Success.”

The *Introduction to Engineering Course Classification Scheme* has been shown to be a valuable tool for the accurate classification of the contents of “Introduction to Engineering” courses. Preliminary applications of the taxonomy have demonstrated its most potent advantage in that it is a powerful resource for curriculum evaluation and reframing [30, 35]. With these two applications in mind, the scheme should prove useful for institutions looking to assess the content of their first-year programs. In addition, schools dealing with transfer credits of general introductory engineering courses or funding agencies that need to specify characteristics of courses within proposals can benefit from utilizing the scheme.

5.4 Applications and Implications

The scheme has been used to evaluate current practices in first-year engineering curricula [34, 35]. One large, public university in the Midwest performed a self-study exercise for six courses that were part of two tracks: common and honors [34]. Participants of the exercise, professors and teaching assistants of these courses, classified their individual section(s) of “Fundamentals of Engineering.” As a result, agreement was found in most of the eight main topics, whether a topic was covered by all or intentionally not covered by all instructors; yet, some discrepancies did emerge. After reviewing the classifications, the group of instructors recommend changes to the first-year curriculum.

For the purposes of demonstrating an *informal* application of the scheme in this article, another university used the scheme to map a recent revision of the course. In an exercise in member checking, instructors mapped the course at the end of the semester based on content they had covered. Another instructor who had not taught this version of the course mapped the course using the course syllabus, course objectives and weekly schedule. As per the rules of classifying a course: if the topic was mentioned or implied in the syllabus or elsewhere, it received a checkmark. Results are shown in Table 2.

Table 2: Application of the Scheme for a first-semester Introduction to Engineering Course

Main Topic	Mapping using course documents	Mapping by instructor	Comments
	Number of topics covered		
ACAD	1	5	Topic checked from course documentation also checked by instructor
COMM	1	4	Topic checked from course documentation also checked by instructor
DESN	5	9	One topic (Research) mentioned in documents; not checked by instructor
ENPR	3	9	Topics checked from course documentation also checked by instructor
ESTT	5	5	One topic (sketching) mentioned in documents; not checked by instructor
GLIN	0	0	
MATH	1	3	Topic checked from course documentation also checked by instructor
PROF	6	7	Topics checked from course documentation also checked by instructor

Almost all content that was gleaned from specific course documentation was indicated by the instructor as content that was covered. Clearly, the goal would be to cover all content mentioned in the course documentation; these results show that, for this instance, this was the case with a few minor exceptions. Notably, the course instructor indicated greater coverage of topics than specified in course documentation. This could be reasonably expected, as the course documentation would give a more minimal list of necessary course requirements rather than a complete and exhaustive list of all material to be covered.

The study resulting in the taxonomy has several implications for future application and research. For example, the applicability of the taxonomy as a tool in the study or revision of curricula is strong – as evidenced by Gustafson [34] and Mohammadi-Aragh and colleagues [35]. The taxonomy can serve as the framework within which existing curricula is studied, with which to study consistency and repeatability among sections of a course, or to revise a course or program.

Future research might include establishing 'course foci,' or classification of courses or programs based on the results of completed taxonomies [30]. Further research into expanding the binary "covered / not covered" choice for each topic into a system that can indicate strong to weak emphasis and the implications of such a revision is anticipated. Finally, further refining the taxonomy to allow for greater dissemination is ongoing.

5.4.1 Transferability within and beyond the United States

The *Introduction to Engineering Course Classification Scheme* was developed within the context of United States curricula, so transferability to contexts outside of the country of origin is a useful question to explore. Recall that while the topics within the taxonomy are grounded within interdisciplinary introductory engineering courses in the first year, no further assumptions are made about the structure of the course. Provided the intended context is an introduction to engineering course, the user is unlikely to face difficulty in applying the tool regardless of whether the course is situated in the United States or elsewhere.

Certain relaxations can be made to the restrictions to apply the *Introduction to Engineering Course Classification Scheme* in other courses. For instance, one could feasibly classify an "Introduction to Electrical Engineering Course" with some limitations. More discipline specific topics will not be found in the taxonomy as advanced concepts specific to the disciplines where not considered within the scope of the study. Using the taxonomy to classify other courses like Statics and Circuits is discouraged for the same reason. In fact, the classification of a non-introduction to engineering course will likely be a mindless activity devoid of any insights.

6. Limitations

One limitation of this work is the possibility that some content within first-year introductory engineering courses was not included in the final revision of the taxonomy, although the use of multiple methods to establish the extensive list of topics should help mitigate this possibility. Regardless, completeness in of itself is a dubious claim with respect to such a taxonomy. Rather, the taxonomy will naturally evolve as internal and external influences (e.g., departmental and ABET criteria, respectively) exert themselves on the first-year engineering experience. On a similar note, others may have qualms about the placement of certain items in the taxonomy, but allowing topics to have complete freedom to shuffle among the eight main topics, as experienced by the investigators, was not productive to the development of the taxonomy.

A further limitation is that these results were found strictly through analyzing institutions and programs within the United States, so the results may exclude content found in different international contexts. However, the context should not be a significant barrier to implementation.

One shortcoming of the scheme that has emerged with testing is the way topics are 'checked' – a binary "yes" or "no" system. This was of interest during a debriefing conference call between the investigators and first-year engineering instructors of a large Midwestern university [30, 34]. The differences among instructors in the multiple sections were noted, and faculty were left to decide what constituted "enough coverage" to constitute a check mark; this can lead to variability among section. To improve the scheme's usability as a tool, the introduction of a measure for "depth of coverage" or "emphasis" of a topic will aid in settling the ambiguity. A 0-3 heuristic was tested at the final testing site where 0 denotes no coverage and 3 would imply the topic is essential to the course; however, the heuristic will need to be tested further for validity [25].

Toward that objective, restructuring the classification method could be beneficial. For instance, the taxonomy lists all the possible programming languages; however, it would be impractical for an introductory course to cover *all* the languages. Thus, if one considers examining the total coverage from the perspective of the eight main topics, then there may be an unintentional "penalty" placed upon the user's course since there is an unequal number of topics in each main category. Engineering Specific Tools/Topics is an excellent example of this phenomenon due to the sheer number of specific engineering topics identified during the Delphi study.

Interpreting results of the completed classification scheme can also appear to be a daunting undertaking in the binary form; this interpretation would involve examining a cloud of checkmarks for trends. Such trends could manifest themselves as skewed coverage in a topic, which the investigators operationally define as *course foci*. The idea of defining *course foci* can be achieved using the scheme since the taxonomy encompasses the content found within introduction to engineering courses. There can be considerable value in mathematically formulating such trends to streamline comparisons between courses. Thus, the result of classifying some arbitrary course would include the ability to describe the course in terms of its foci. This application of the classification scheme could be useful to funding agencies and universities awarding transfer credit.

7. Conclusion

Through this NSF-sponsored study, we have developed a classification scheme for first-year "Introduction to Engineering" courses [36]. Multi-stage content analysis mixed with a three round Delphi Study was employed to construct a complete taxonomy, including culling topics from syllabi available online, holding a focus group at Frontiers in Education, a national engineering education conference, and a three-round Delphi study. The Delphi study was used to survey participants in three rounds before reaching consensus on the final iteration of the classification scheme. A culminating workshop was held at a national level conference, the First Year Engineering Experience conference, where participants tested the scheme by classifying first year engineering courses at their home institution – followed by two workshops to serve as final opportunities to revise the taxonomy.

We anticipate the impact of the scheme will allow universities, community colleges, and funding agencies to use the taxonomy to accurately determine specific course content when considering credit awarded for transfers, to develop and evaluate introductory engineering programs, and to identify and fund efforts toward filling assessment gaps.

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