# The Development of a Framework for Curriculum Integration

Michele Miller
*School of Engineering*
*Campbell University*
Buies Creek, NC, USA
mhmiller@campbell.edu

Anastasia M Rynearson
*School of Engineering*
*Campbell University*
Buies Creek, NC, USA
amrynearson@campbell.edu

***Abstract*— This work-in-progress paper describes the initial stages of the development of a framework to understand learning outcomes related to technical content, professional skills, tools, and values across an entire engineering undergraduate curriculum. This iterative process of development has been undertaken by the mechanical engineering faculty of a new engineering program in order to map and plan for an overall integrated curriculum. The current status of the framework and intended future work are detailed.**

***Keywords—integrated curriculum, program evaluation, framework development, learning outcomes***

## I. INTRODUCTION

Across the United States and the world, engineering colleges are embarking on curriculum revisions to address the evolving needs of engineering students, including how they learn, and engineering employers, including the desired attributes of engineering graduates [1]. The NAE Engineer of 2020 [2], ASME Task Force 2030 [3], the Carnegie Research Institute [4], and others have highlighted this need for change. Due to the high demand for engineers, new engineering programs are being offered at many universities nationwide. Campbell University, a small rural liberal arts institution, houses one of these new engineering programs. With no inertia to overcome, the new programs have a unique opportunity to innovate and/or adopt the best practices of others. This can be a daunting task; there are many engineering programs and a plethora of research concerning engineering education practices and principles [1, 5-7]. At a minimum, we must understand how our curriculum compares to other programs. We will be undergoing ABET accreditation [8], so assessment and continuous improvement are important goals.

Whether revising or starting new, many programs may engage in similar processes: benchmarking curricula against other institutions, making relatively minor adjustments in response to ABET assessment, identifying and mapping curriculum threads that span multiple courses. All of these processes can be improved through the use of instruments. This work-in-progress paper describes the development of a framework for documenting the content of an entire mechanical engineering curriculum. There are four goals for this project: 1. Develop a framework that can be used internally and externally to map student outcomes. 2. Share the development of the framework as a model for other institutions, both new and established. 3. Share the framework itself as an example or initial point for future development. 4. Gain feedback from the engineering education community to improve the framework itself. This paper will focus on goals 2 and 4, sharing the initial and current stages of the framework development and soliciting feedback from the engineering education community.

## II. BACKGROUND/MOTIVATION

Campbell University is a small rural private liberal arts intitution with a religious tradition. While it is not the first such institution to house an engineering department, there are not many and the purpose and context of the university create a unique engineering experience. An individualized framework, drawing on available literature and frameworks for common engineering programs, will allow the department to understand the full curriculum, including the strengths and weaknesses unique to the program. More broadly, the framework and process for creating a unique framework can be applied to other programs and institutions looking to understand their engineering program in a holistic way. Campbell's School of Engineering offers a general engineering degree with concentrations in chemical engineering, electrical engineering, and mechanical engineering (ME). Thus far, we have worked on developing a curriculum framework for the ME concentration as a pilot project before expanding the effort to all of the concentrations.

A framework for documenting curriculum content is useful both in the development of a new or revised curriculum and in the delivery and maintenance of it. During curriculum development or revision, such a tool could be used to negotiate curriculum priorities, to plan transitions between pre-requisite and subsequent courses, and to identify gaps that need filling. During curriculum implementation, the framework could be used to show a new instructor how their course fits into the curriculum or to troubleshoot poor performance in an ABET learning outcome.

Integration of important content across multiple courses is particularly challenging. In concept, integration always seems like a great idea, but the execution presents problems. Sequential courses are often taught by different instructors. Even with regular communication, for complex topics, it is

978-1-5386-1174-6/18/$31.00 ©2018 IEEE

difficult to communicate expectations of where student learning will begin and end in each course. Also, textbooks often treat each subject in an isolated way and thus do not document the inputs and outputs of integrated topics. The problem becomes exacerbated when a course changes hands to a new instructor.

The motivation for sharing our work with the engineering education community differs from the motivation for developing the framework. The full framework and the results are intended primarily for our internal use and use in continuous improvement and assessment initiatives. The use of a framework is not a new or innovative method for understanding, revising, or assessing a curriculum. Our framework includes existing methods and frameworks, combining them for the specific context of this institution and its new engineering program. We are sharing our process so that the wider engineering education community can see how to undergo a similar process. We will also offer our framework as a starting point for others to adapt. This transparency in process and product can help other engineering departments, both new and established, to develop their own internal frameworks.

## III. Theoretical Underpinnings

Developing a framework to track the desired outcomes throughout a curriculum is not a new idea. A number of existing frameworks informed the development and implementation of our framework.

### *A. CDIO Syllabus*

The CDIO (Conceive, Design, Implement, Operate) Initiative is an open-source collaboration to identify and promote best practices in engineering education [1]. The organization has developed a syllabus that includes knowledge, skills, and attitudes that can be used as a model for engineering programs. The CDIO Syllabus focuses on the practice of all engineers rather than discipline-specific technical content. The syllabus presents learning outcomes at four levels of detail. At Level I, the outcomes are:

1. Disciplinary Knowledge and Reasoning
2. Personal and Professional Skills and Attributes
3. Interpersonal Skills: Teamwork and Communication
4. Conceiving, Designing, Implementing and Operating Systems in the Enterprise, Societal and Environmental Context.

Levels II through IV expand these to more detail [1]. For example, outcome 1 expands to:

- 1.1.1 Mathematics
- 1.1.2 Physics
- 1.1.3 Chemistry
- 1.1.4 Biology
- 1.2 Core Engineering Fundamental Knowledge
- 1.3 Adv. Eng. Fund. Knowledge, Methods and Tools

This is the least detailed outcome. It includes, but does not specify, engineering fundamental knowledge. The remaining Level I outcomes are much more detailed. For example, outcome 2 expands to five outcomes at Level II:

- 2.1 Analytic Reasoning and Problem Solving
- 2.2 Experimentation, Investigation and Knowl. Discovery
- 2.3 System Thinking
- 2.4 Attitudes, Thought and Learning
- 2.5 Ethics, Equity and Other Responsibilities

Each of these in turn has 4-7 sub-outcomes, for a total of 26 Level III outcomes. Level IV has 121 outcomes.

The outcomes in the CDIO Syllabus were identified via research and have been refined and validated through a variety of methods with stakeholders including faculty, students, employers, and industry experts, among others. Graduates of engineering programs all around the world should attain these skills, according to the CDIO Initiative.

### *B. NCEES FE Exam Specifications*

The NCEES FE exam specifications is a detailed set of core content that is deemed important by the community of professional engineers [9]. These specifications cover the technical content and are discipline-specific for the major engineering disciplines, including Chemical, Mechanical, Civil, Electrical, and others, and offer a list of specifications for general engineering degrees under the Other designation. These content specifications inform the exam that is used to determine whether an engineer is considered an engineer in training and eligible to eventually become a licensed professional engineer.

### *C. ABET EAC Criteria*

ABET has a number of outcomes that graduates of accredited engineering programs are expected to meet [8]. In the United States, most engineering programs choose to undergo ABET accreditation. The CDIO Syllabus has been mapped to ABET Student Outcomes (from Criterion 3) and was found to have a strong correlation to all outcomes [1, p. 57]. In our project, the ABET learning outcomes are not explicitly listed but rather are included through the prior mapping against the CDIO Syllabus.

### *D. ITU Chart*

The framework goes beyond a list of knowledge, skills, and practices. For the framework to be useful, it needs a method of implementation that allows the knowledge, skills, and practices to be tracked through the curriculum. A method proposed by the CDIO Initiative, the Introduce-Teach-Utilize (ITU) chart, is used in the continued development and implementation of the framework. In an ITU chart, each course is analyzed and for each course, all relevant outcomes are marked with I, T, or U as described in Table I.

TABLE I. Definitions of Introduce, Teach, and Utilize (adapted from [1, p. 87])

| | **Learning Outcomes** | **Learning Activities** | **Assessment** |
|---|---|---|---|
| Introduce | Probably not an explicit outcome. | Topic is included in an activity. | Not assessed. |
| Teach | Must be an explicit learning outcome. | Included in a compulsory activity. Students practice and | Students' performance may be assessed. May |

| | Learning Outcomes | Learning Activities | Assessment |
|---|---|---|---|
| | | receive feedback. | be graded or ungraded. |
| Utilize | Can be a related learning outcome. | Used to reach other intended outcomes. | Used to assess other outcomes. |

## IV. METHODS

### A. Framework Validation

Our goal is to develop a framework that allows for robust and rigorous tracking of student outcomes throughout the curriculum. A framework that meets this goal must be validated through a variety of means to ensure it encompasses the intended outcomes and that these outcomes are important aspects of educating undergraduate engineers [10]. The framework has multiple avenues of validation used throughout its development.

The initial framework has been built upon published, research-based frameworks including the CDIO Syllabus and the NCEES FE exam specifications. The framework is intended to track skills, knowledge, and behaviors taught to students as they progress though the curriculum. It prioritizes the skills, knowledge, and behaviors that an engineering graduate should possess to be an effective engineer. The core of the framework, the CDIO Syllabus and NCEES FE exam specifications, provide an accepted list of skills and knowledge that engineering graduates can be expected to attain.

Members of the faculty are considered experts in the courses they teach. Of the current faculty working on the project, two have experience in engineering education research, one has been involved with curriculum benchmarking for CDIO at a prior institution, and one has experience as an ABET program evaluator. The faculty have experience in developing and assessing curricula at a program level, adding to the validity of the framework development process.

Our faculty is also continuing to grow. This will allow additional validation from new faculty as they are introduced to the framework and asked to review and implement it. Additional expert validation will be sought from two main groups: industry, accessed through the Engineering Advisory Board of the school, and engineering education professionals, accessed through conferences and similar venues such as the 2018 FiE conference. Potential employers of our students provide input on the skills and tools they expect our engineering graduates to be familiar with, while engineering education professionals can provide input based on their programs, experiences, and expectations.

### B. Development Process

This framework is in the process of creation through an iterative cycle of development and faculty consensus. Every other week, the faculty meets to consider a specific aspect of the framework. The current state of the framework development process is detailed in the following section.

## V. CURRENT STATUS

To start, we created an Excel spreadsheet with rows for outcomes and columns for each course. We added the CDIO Syllabus Level 3 outcomes, which produced 124 rows in the spreadsheet. Level 2 was not as detailed while Level 4 was far too detailed and created over 600 rows. We then identified gaps in the CDIO Syllabus, areas where we wanted more detailed tracking of student outcomes. As mentioned above, the Syllabus does not specify disciplinary engineering knowledge. Thus, we extended outcome 1.2 (Core Engineering and Fundamental Knowledge) by adding outcomes from the Fundamentals of Engineering exam. We combined the overlapping outcomes from the Mechanical and Other exams, adding 160 rows. A few planned courses in the curriculum—Manufacturing, Quality, and System Dynamics are barely addressed in the FE; so, content rows were added for those courses (37 more rows).

Additional content has been added to the framework that is specific to our context. At our departmental retreat the previous spring, we identified tools and software that we anticipated would span multiple courses. We took that list and added it to the spreadsheet (15 rows software, 44 rows tools and equipment). Finally, before the first class of students arrived, the founding faculty and staff of the new School established eight core values (community, excellence, ethics, professionalism, relevance, resilience, ownership, service) that are intended to pervade all aspects of the School, including the curriculum; thus, eight more rows were added.

Once the initial expansion was complete, we looked for overlap amongst outcomes (computational tools was one area) and outcomes beyond the scope of our curriculum (such as communications in other languages) and removed seven rows. The total at this point is 381 rows. Next, the mechanical engineering faculty individually reviewed the list and assigned priority from 1=cut to 3=keep. While we are hesitant to permanently delete anything that remains, this will likely remove a couple dozen rows.

In addition to content revisions, we added a column for co-curricular experiences and elective courses. Entrepreneurship, leadership, and other areas can be important aspects of an undergraduate engineering education. These areas are in the CDIO Syllabus and are available to students through participation in a variety of activities, from the NAE Grand Challenges Scholars Program [11] to workshops and participation in student organizations. These experiences further develop students into employable engineers. The additional column will allow us to track the outcomes from these experiences and communicate their content to stakeholders including industry partners.

Once the content for the framework was considered reasonably complete, we assigned a faculty member to consider each course column and identify the type of coverage for that course, using I, T, and U notation as shown in Table II. We have adapted the CDIO Initiative's ITU chart method to better serve our needs. Another dimension to the designation is the overall importance to the course. Lowercase indicates that the course includes this topic but that it is not a core component. Uppercase indicates that the topic is consistently used throughout the course. Italic and bold means the topic is integral to the course and a major component.

TABLE II. ITU CHART ADAPTATION

| | Concept | Definition |
|---|---|---|
| I | Intoduce | Concept is introduced but not really taught or used in the course. |
| T | Teach | Students are expected to learn the concept in the course. |
| U | Use | Students are expected to be able to use the concept in the course. |

Different kinds of analysis become possible based on the array of I's, T's, and U's. For example, the number of instances in each row can be counted. From this, we might learn if a topic is introduced but then never subsequently taught or used. Conversely, an upper division course might use a topic that was never previously introduced or taught. The number of instances in each column can also be counted. This would give insight as to whether a course introduces many topics without going into depth in any. Looking at the whole array, we can readily see which topics get the most attention throughout the curriculum and which the least. Also, moving across a row (and therefore across the outcome), we can look for a progression of I's, followed by T's, and followed by U's.

## VI. FUTURE WORK

This framework is a living document that will be revised as the curriculum is developed, implemented and iterated. It is specific to our context which includes a general engineering degree with multiple concentrations, a project-based curriculum with small class sizes, regional employers with a manufacturing focus, and a university-wide emphasis on values. In the short term, we will seek input on the curriculum content from our industry partners. The professional skills, software, equipment/tools may be of particular interest. We also intend to survey other engineering educators (at the FiE meeting and elsewhere) for their input.

The framework is a starting point for course level learning outcomes. We plan to have individual instructors drill down to the CDIO Level 4 learning outcomes. For example, the Level 3 outcome "3.1.3 Team Growth and Evolution" has four components at Level 4: Strategies for reflection, assessment and self-assessment; Skills for team maintenance and growth; Skills for individual growth within the team; Strategies for team communication and reporting. Five courses in the ME concentration currently address Team Growth and Evolution; instructors will identify which Level 4 outcomes they address. Another example of an area for more detail is specific MATLAB commands taught in each course.

For courses that are taught by different instructors, the Level 4 learning outcomes will help instructors to understand which components are integral to the course and what students should be expected to encounter during the semester. Faculty will retain flexibility to teach the course as they wish, but they will also be aware of what they should expect students to be able to do from prerequisite courses and know what other faculty will expect students to be capable of upon completion of any course they teach. New instructors also offer an opportunity to test the initial assessment of the course and alter expectations. Changes to course outcomes are anticipated due to faculty autonomy, but these changes can be made with considerations to the rest of the curriculum and whether the outcomes are needed during that course.

In addition to the immediate uses of the framework for course and curriculum development, the framework has the potential for further impact. For example, it facilitates the development of more granular course learning outcomes. It also frees instructors to be less reliant on the organization of topics in the textbook. Finally, it makes it more possible for the curriculum to be adaptable and flexible. Rather than changing course titles or credits or sequence, both large and small adjustments in content can be envisioned and strategized without requiring university approval and changes to the registrar's degree requirements.

At times during its development over the past school year, the framework became overwhelming to the point of demotivation. Thus, we recommend focusing effort on one or two topic areas that are of interest to everyone (such as software tools). Then flesh out those outcomes and test how that small part of the framework might be useful.

## REFERENCES


[1] E. Crawley, J. Malmqvist, S. Östlund, and D. Brodeur, *Rethinking Engineering Education: The CDIO Approach*. New York: Springer, 2007.

[2] National Academy of Engineering. *The Engineer of 2020: Visions of Engineering in the New Century*. Washington, DC: The National Academies Press, 2004. https://doi.org/10.17226/10999.

[3] ASME Vision 2030 Task Force, "Vision 2030: Creating the Future of Mechanical Engineering Education". ASME Center for Education, USA, Final Rep., 2011.

[4] The Carnegie Clasification of Institutions of Higher Education. [Online]. Available: http://carnegieclassifications.iu.edu/

[5] A. Johri and B. M. Olds, Eds., *Cambridge Handbook of Engineering Education Research*. New York, NY, USA: Cambridge University Press, 2014.

[6] R. Felder and R. Brent, *Teaching and Learning STEM*. San Francisco, CA, USA: Jossey-Bass, 2016

[7] D. E. Goldberg, M. Somerville, and C. Whitney, *A Whole New Engineer: The Coming Revolution in Engineering Education*. Douglas, MI, USA: ThreeJoy Associate, Inc., 2014.

[8] ABET: Accreditation. [Online]. Available: http://www.abet.org/accreditation/

[9] NCEES: Advancing licensure for engineers and surveyors: FE exam. [Online]. Available: https://ncees.org/engineering/fe/

[10] K. A. Douglas and Ş. Purzer, "Validity: Meaning and relevancy in assessment for enigneering education research," *J. of Eng. Ed.*, Vol. 104, no. 2, Apr. 2015, DOI 10.1002/jee.20070

[11] NAE Grand Challenges for Engineering: NAE Grand Challenges Scholars Program. [Online]. Available: http://www.engineeringchallenges.org/20419.aspx