The World Needs More Complete Engineers: Developing Students' Non-Technical Skills

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Abstract

The world needs qualified engineers and leaders that possess strong technical knowledge in their field of study combined with a set of non-technical skills that allows them to solve problems of global importance. Our Complete Engineer® program strives to create an environment that assists students in enhancing specific non-technical competencies in coordination with a strong technical foundation. The purpose of this paper is to provide context and justification for developing the Complete Engineer® program, overview the framework for the program, summarize the six Complete Engineer Competencies: Inclusive Excellence, Communication, Self-management and Leadership, Civic Responsibility, Teamwork, and Professionalism and Ethics, and to serve as a guide for engineering programs that have similar student development objectives. We conclude the paper with our next steps and future goals.

Keywords

Complete Engineer, student development, non-technical skills

Introduction

The world needs qualified engineers that are competent technically, personally, and professionally. An engineering graduate with a solid technical foundation is empowered to provide solutions to current and emerging challenges. However, a technical foundation buttressed with personal and professional skillsets provides engineering graduates with a distinctive edge when solving problems of global importance. The College of Engineering (COE) at the University of Nebraska- Lincoln (UNL) is committed to developing engineers professionally, personally, and interpersonally through its Complete Engineer® program. The purpose of this paper is to describe the process UNL COE followed to develop this program so that others interested in building similar programs might benefit from lessons learned.

As part of the COE's holistic approach to engineering education, the Complete Engineer® program works in tandem with curricular programming to develop its undergraduate students in six core non-technical competencies. These six Complete Engineer® competencies are vital skills engineers need in today's dynamic workforce and were identified through a combination of industry input and an extensive review of engineering education literature. The result of this blend of critical technical skills and essential non-technical skills is that our students are positioned to graduate as well-rounded, successful members of their professions.

Literature Review

The concept of developing students' "soft skills" in higher education is certainly not a new one. Various institutions have aimed to formalize how they develop their student's non-technical skills. These are skills that institutions deem important for their students' future. For example, the University of Central Oklahoma (UCO) relied on the theoretical base of transformative learning to develop their Student Transformative Learning Record (STLR) [1]. The transformative learning theory is based on the work of Mezirow which argues that in order for authentic transformation to occur, learners need to reflect on their relationships with themselves, others, and the world they live in. Learners may have transformative experiences if they are willing to explore other ways of thinking [2]–[4]. The STLR focuses on six tenets that UCO employs to support their students' growth. Other examples of institutionalized efforts are centralized through student support offices or career services. For example, the University of Colorado Boulder's Skills for Success program assists students in recognizing skills they have and in learning skills that they lack [5], and the University of Minnesota's Office for Student Affairs has adopted Student Development Outcomes that go beyond typical program outcomes and help prepare students to be "engaged and effective citizens."

Within the context of engineering colleges, we find numerous models on how they develop their students' non-technical skills, three of which are frequently referenced in the literature. First, some programs aim to develop students' non-technical skills by developing faculty's understanding and implementation of instructional approaches. For example, the School of Engineering of the Polytechnic of Porto reported on their efforts to boost students' non-technical skills through the implementation of active learning [6]. One study reviewed the promotion and teaching of non-technical skills in higher education across five European countries [7]. The researchers grouped skills that engineering students need into five categories: Technical, Metacognitive, Intrapersonal, Interpersonal, and Problem solving. They then presented groupings of best pedagogical practices that may be integrated into the curriculum, such as problem-based learning, project-based learning, game-based learning, and gamification, among others.

A second model referenced in the literature is focused on developing student's non-technical skills through co-curricular activities. The literature indicates that students' involvement in co-curricular activities greatly influences their retention and development [8]–[10]. For example, one case study on undergraduate engineering at the Massachusetts Institute of Technology (MIT) identified twenty-two categories of co- and extra-curricular activities that are shown to develop at least one skill that is relevant to engineering education [11]. Another study used dialogues with engineering students from three institutions and found engineering students that were involved in co-curricular activities on leadership and ethics were positively impacted [12].

The third model for developing students' non-technical skills is requiring stand-alone courses or workshops that are integrated into the curriculum. For example, one study [13] demonstrated the effectiveness of integrating teamwork and soft skill-focused workshops into a manufacturing systems course. These students showed improved team performance after going through a "soft skills" workshop. Another study investigated "soft-skill" focused single class sessions within engineering courses and found an increased ability for students to utilize soft skills [14].

Rooted in Kolb's Experiential Learning Theory, our Complete Engineer® program blends these models [15]. Kolb's four-stage model describes how we can rely on reflection to translate one's experience. The theory upholds the importance of experiential activities where the learner makes links between each of the four stages: 1) Concrete Experience: the place in which the learner is activity experiencing an activity; 2) Reflective Observation: the place where the learner reflects on the experience; 3) Abstract Conceptualization: the place where the learner conceptualizes the theory of what is observed; and 4) Active Experimentation: the place where the learner plans to test the theory.

Why the Complete Engineer®?

Many colleges of engineering have student development programs focused on what are commonly referred to as "soft skills." This professional development oftentimes focuses on one or a few key skills such as leadership, teamwork, and project management—all necessary skills for a newly minted engineering graduate. Similarly, many businesses have internal training to enhance the professional skillset of their workforce. The implicit message behind these kinds of programs, both in colleges and in businesses, is that ongoing professional skill development is an expectation of professional performance and advancement. As we set out to create our own student development program, our college leadership sought to answer two key questions: What can we do to develop our students in tandem with enhancing their technical knowledge and skill? And how can we do so in a consistent, equitable, and efficient manner?

The investigative efforts to answer these questions began with college leadership visiting stakeholders and employers of COE students to discuss their perceptions of COE graduates. Through these visits, a few key themes emerged that were related to students' mastery in two domains. We labeled these domains Technical Mastery and Professional Mastery. Technical Mastery refers to the foundational science, math, and engineering knowledge and skills needed to do the work of an engineer. Professional Mastery refers to non-technical skills like leadership, communication, and teamwork that are necessary for success and advancement in a professional setting.

The feedback from stakeholders and employers was that COE graduates were strong in terms of Technical Mastery: They were technically capable, well trained, and well educated in the practice of engineering. There were a few suggestions and anecdotes from stakeholders indicating that the students needed "one more class in ____." Still, the technical curricula were reported to be sound. However, the feedback we received from stakeholders and employees was that there was wide variability in the degree to which our students were prepared in terms of Professional Mastery. At the time, our students were learning leadership, communication, and teamwork through a combination of curricular, co-, and extra-curricular offerings like communication courses, engineering clubs and competitions, and capstone experiences. The curricular, co-, and extra-curricular offerings were working sufficiently for some, but not all, of our graduates.

Additionally, as college leadership reflected on what it meant to be a Complete Engineer®, they came to see that something was missing from the two-dimensional framework of Technical Mastery and Professional Mastery. They felt strongly that Personal Mastery—knowledge, skills, and values like self-management, civic responsibility, engineering ethics, and inclusivity—was a major contributor to professional advancement and enables engineers to have a broader impact on the world. Thus, a three-dimensional framework of Technical Mastery, Professional Mastery, and Personal Mastery became the foundation of the Complete Engineer®. In general, our curricula were designed to address Technical Mastery. Our curricula and co-curricular activities were designed to address Professional Mastery. We were, however, less deliberate in attempts to address Personal Mastery.

One core assumption made during the conceptual stages was that as students developed and came to understand their status along each dimension, they would become aware of the ways in which they still needed to grow. We envisioned training and development programs that would be tailored to each person, expecting that the dimension most in need of growth would be students' priority for development and attention. In our attempt to develop our students into "Complete Engineers", none of us believed that our thinking or development of these ideas were complete. There was angst that we were only able to grasp and describe a portion of the problem and opportunity that we were seeing. We knew each of these dimensions are dependent and inter-connected: A strict mathematical or Boolean approach fails to describe or capture the interplay between the dimensions. As such, we viewed each student as a "whole person," not just a collection of attributes aligning with these three dimensions. Here began our efforts in designing, developing, piloting, and implementing The Complete Engineer® program.

First, the underlying philosophy was that good engineers have mastered the technical competencies needed for their profession while also demonstrating the non-technical skills needed to serve the public effectively and to solve global engineering challenges. Second, the literature on student development clearly indicates that a primary method for preparing graduates for sophisticated problem-solving is through the process of pairing non-technical skills with a strong technical foundation both within the curriculum and through co-curricular activities. And third, we sought extensive industry input on the skills that they believe are needed for a well-rounded engineer in terms of Technical, Professional, and Personal Mastery. With these influencing factors in mind, six non-technical competencies connected to the three Mastery dimensions were selected. The six Complete Engineer® competencies are Inclusive Excellence, Communication, Teamwork, Self-Management and Leadership, Civic Responsibility, and Professionalism and Ethics.

The Early Years

After gathering the feedback from partners in industry about the variability in our graduates' Professional and Personal Mastery, leaders in the college set out to map the extent to which these elements were part of our students' experiences while at UNL. It became clear that elements of Professional Mastery were incorporated into courses (e.g., communication courses, capstone experiences) and co- and extra-curricular experiences (e.g., internships, student organizations). However, Personal Mastery was not formally part of our students' progression through their degree programs. The first major step taken to formally incorporate the Personal Mastery dimension into undergraduate students' experiences while at the university was creating a new first-semester seminar course that emphasized the Personal and Professional Mastery dimensions. A primary goal was to prompt students to use reflection and self-evaluation in connection with setting personal and professional goals that would form the basis of a personal and professional development plan. This first-year seminar course, ENGR 10, became the primary vehicle for exposing new students to the Complete Engineer® program. In addition to providing a general orientation to the COE and helping students transition to the collegiate learning environment, ENGR 10 introduced the Complete Engineer® competencies. Students learned what the competencies are; why they are important to engineering, construction, and computing professionals; and how to access existing opportunities to grow in the competencies.

The Complete Engineer® Conference was our marquee opportunity for all students to further connect with the program. The first two conferences (2016 and 2017) were 2 ½ day events. Attendees listened to speakers, toured the facilities of the college's industry partners, and practiced using their Complete Engineer® competencies. As the number of attendees grew after the first two years, the conference shifted to having fewer tours, more workshop sessions, and more industry involvement. Unfortunately, we did not host the conference in 2021 due to COVID-19 restrictions, and the decision was made to also not host the conference in 2022. In addition to the conference, our college advising and career development staff provided guidance and coaching within the framework of the Complete Engineer®. This important one-on-one work is foundational to the program and continues to this day.

The Groundwork

As the support for the Complete Engineer® within the college grew, the decision was made to form a committee of faculty and staff that was dedicated to continuous improvement of the program, especially in terms of inclusivity and alignment with the college's strategic goals. The committee was comprised of faculty from each department and staff already working on the Complete Engineer® or in roles critical to the success of the program. The two biggest outcomes from this committee were the competency growth framework and the revised set of competencies (see Table 1). Our growth framework is grounded in Kolb's Experiential Learning Theory [15] and has three levels: Exposure, Engagement, and Transformation. After reaching a consensus on how to define these levels within the program, a subcommittee used those definitions along with the definitions of the competencies to draft a full set of descriptors for the expectations of each competency and each level.

Table 1. Initial and Revised Competencies

Initial Competencies	**Revised Competencies**	**Definition of the Revised Competency**
Intercultural Appreciation	Inclusive Excellence	We recognize and embrace our differences and make equity and inclusion a priority. We know diversity of people and ideas empowers us to address challenges and leads us to creativity and innovation.
Leadership	Communication	We effectively connect through respectful collaborative exchanges of information and ideas. We build relationships and achieve successful outcomes through our many forms of communication.
Self-management	Self-management and Leadership	We take responsibility for our own behavior and well-being as we act with integrity to serve the needs of our communities. We responsibly prioritize goals

		and use initiative, motivation, empathy, openness, and organization to move toward shared goals.
Service and Civic Responsibility	Civic Responsibility	We have a positive impact on the world around us by being engaged, solving problems, and making a difference. We create a better future by actively contributing to our professions and communities.
Teamwork	Teamwork	We create accountable, engaged, productive teams that collaborate across disciplines. We respect the contributions of all members and their unique roles and perspectives as we work toward objectives.
Understanding of Engineering Ethics	Professionalism and Ethics	We are trusted and recognized for our integrity, as we work to improve the health, safety, and welfare of society. We behave responsibly, ethically, and respectfully.

The level of detail built into the competency growth framework was a result of our desire to create a formal system for assessing and credentialing students' participation in the Complete Engineer® through digital badges, a set of micro-credentials, or something similar. A separate subcommittee gathered information about various credentialing options. At the same time, we sought feedback from students and industry partners about what they believed would be most useful for students to demonstrate their skills to potential employers or vetting applicants, respectively. Those groups expressed a strong preference for having credentials represented on the students' official university transcripts. Documentation through transcripts was an attractive option for us, but presented some challenges related to the university's constraints around what can be recorded on transcripts.

The Expanded Vision

The Complete Engineer® was further elevated in 2019 through a college-wide strategic planning process. Throughout that year, a group of COE faculty, staff, students, and administrators met several times to outline a new vision for the college and discuss the steps that the college would need to take to achieve its strategic goals. The college strategic planning process overlapped with the release of two key documents: the report of the N|150 Commission and the university's N2025 strategic plan. The former outlined the university's core aspirations for the following 25 years, and the latter was a five-year plan to work towards those aspirations. Several pieces of the university's goals aligned with the Complete Engineer®, namely expanding students' ability to engage in experiential learning; expanding engagement in community, industry, and global partnerships; focusing on "future-ready" skills in addition to technical competence; and prioritizing inclusive excellence. The combination of the internal momentum behind the Complete Engineer® and the alignment between it and the N|150 Commission's report resulted in a college strategic plan anchored in the grounding philosophy of the Complete Engineer®, one that intends to ensure all individuals enrolled in or employed by the College are becoming "Complete Engineers®."

With the incorporation of the Complete Engineer® into the strategic plan, there was broad recognition that we needed to expand our capacity to engage students in the program and prioritize the process of formalizing and documenting students' participation. Using the previously described competency growth model as a guiding framework, we set out to build a sustainable program that provided a structured path for students to grow in the competencies while also being flexible and inclusive of all our students, regardless of personal backgrounds, present circumstances, or future goals. The results of several rounds of discussions were (1) a guarantee that undergraduate students would be Exposed to all competencies through their coursework, (2) an expectation that Engagement and Transformation would result from a combination of in-class and co- and extra-curricular experiences, and (3) a plan for assessing and documenting induvial students' participation in the program through the university's Learning Management System (LMS; Canvas).

The decision to guarantee Exposure and emphasize the importance of co- and extra-curricular experiences for reaching the Engagement and Transformation levels was especially important for achieving our aim to make the program as flexible and inclusive as possible. There are innumerable potential paths for growth in each of the competencies, and our goal was to develop a program that could accommodate all students, regardless of their individual path for growth. As a result, our mechanism for assessing students' Engagement and Transformation centers on reflection resulting from self-initiated experiences. In the formalized portion of the reflection process, students identify the experiences they see as contributing to their growth in a competency and respond to a series of questions about how those experiences have impacted them. The recently initiated plans for implementation of this process are described in the next section.

The Future

We are now in the early days of a new era of the undergraduate Complete Engineer® Program. This year's matriculants were automatically enrolled in a Complete Engineer® "course" on Canvas, and subsequent cohorts will be added in the coming years. During this phase-in process, more senior students have the option of being added to the Canvas course if they would like to submit for certification at the Engagement or Transformation levels. This Canvas course serves as the submission portal for student reflections as well as a repository of resources related to the competencies.

We use the Assignments structure within Canvas to manage students' reflections. The reflection prompts and rubrics outlining the expectations for meeting the Engagement and Transformation level for each competency are available as 12 separate assignments. All reflections submitted through Canvas are reviewed and scored with a rubric, and students are given feedback for making improvements if their reflection is scored as being below expectations. When a reflection is scored as meeting expectations, the student is given a code to enroll in the corresponding zero-credit Complete Engineer® course so that their achievement will be part of their official academic transcript.

The reviewing and scoring process is done by a designated group of faculty and staff known as the Complete Engineer® Fellows. The Complete Engineer® Fellows were selected from a group of applicants based on their commitment to supporting students' growth in the competencies and prior involvement with undergraduate co- and extracurricular activities. During their two-year commitment, the Fellows are responsible for reviewing submitted reflections, coaching students one-on-one, and generally advocating for the Complete Engineer® program. The inaugural cohort of Fellows has 10 members, and we plan to grow this group as the number of students formally integrated into the program expands.

In keeping with the college strategic plan, the Complete Engineer® will eventually incorporate all undergraduate students, graduate students, faculty, and staff in the college. The graduate student version of the Complete Engineer® was introduced at the start of this semester. In future years we will introduce Complete Engineer® programming for faculty and staff as well. We firmly believe the combination of a strong technical foundation and the Complete Engineer® competencies will position the Nebraska Engineering community to drive economic development in the state and region while solving problems of global importance.

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