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A Multi-Decade Response to the Call for Change

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Abstract

Engineering and society have always been intertwined, especially with the accepted realization of technology's significant and rapidly increasing influence on the evolution of society. As a profession, engineering has a vital role in sustainably meeting needs and exploring opportunities that are ever changing and evolving. As societal and industry needs have evolved, engineering education itself has raised the call several times for evolving the way engineers are educated; however, the recent history of engineering education is, overall, one of missed opportunities. This was brought to a headline recently as ASEE leadership authored an article entitled "Stuck in 1955, Engineering Education Needs a Revolution." Those words say it all. We see a need for a revolution in engineering education that looks at developing a whole new engineer that is equipped to operate in the age of information and Industry 4.0. This is vital to not only the field of engineering but for society.

This paper parallels the calls for change in engineering education with the development story of a multi-disciplinary engineering education model that is often referred to as a beacon of light for change in engineering education. As is highlighted in the currently ongoing ASEE workforce summit series, the world of engineering is shifting beneath our feet. The world of engineering education must shift with it or face irrelevancy. The future iterations of this program are focused on developing graduates with digital savvy, new skills in innovating and collaborating, problem framing expertise, and horizontal leadership skills, while putting emphasis on the impacts in the economic development of rural regions.

In the initial stages, 1990's–2000's, the program's faculty spent time innovating in courses and curricula trying to shift towards the recently released ABET 2000 student outcome criteria in a rural community college setting. The mid-2000's brought the development of a multi-disciplinary upper division university satellite program that embraced the Aalborg (DK) model of PBL. The new multi-disciplinary program had ABET outcomes at its core, focusing on the development of a whole new engineer, especially developing innovative strategies to intentionally promote growth of the professional person. By 2020, the program had achieved disruption, earning an ABET innovation award and being named an "emerging world leader in engineering education" in the Reimagining and Rethinking Engineering Education report. The latest evolution of the program combines on-line learning and work-based learning for a sustainable model that serves a culturally diverse nationwide audience of community college completers.

This is a story of innovative curricula putting team-based project learning at its core. Promising strategies addressed in the paper include ABET outcomes, reflection, identity building, metacognition, teamwork, industry PBL, recruiting, learning communities, and continuous improvement. The conclusion puts a spotlight on where the program and engineering education in the U.S. needs to journey next.

Introduction

Throughout the past few decades, national/international reports and research continually outlined the significant role technology plays in contemporary society and global challenges. Engineers play a vital role in meeting these societal needs through innovation and technological solutions. This role is increasingly evident and is constantly evolving as we experience rapid rates of technological changes and increased utilization in every aspect of daily life. At the same time, the body of engineering and technological knowledge is growing exponentially. We interface with knowledge in a way that has shifted from an engineer mindset of expertise through acquisition of knowledge to how knowledge is accessed and incorporated into engineering solutions. This combined with a need for more engineers and the need for the demographics of engineers to match that of society's has led to over three decades of calls for change in engineering education to take a proactive response to the ever-increasing rate of societal change [1]. Now more than ever engineering educators need to explore and innovate with models and pedagogical approaches that will move engineering education systematically into positions to meet these rapidly changing needs.

While studies, concept position papers, and reviews of innovative approaches are not new in the literature, this paper will explore one program's journey in parallel to changes in the national engineering education as it went from an initial focus on regional student access to responding to calls for change to becoming an internationally recognized emerging model for engineering education. Of value to the broader engineering education community is not only the process of engineering education innovation it is also the pedagogical and curricular models developed that serve for consideration and adaptation to provide that engineering education needs to continue to incorporate to evolve to meet societal needs.

Traditional engineering educational models receive initial calls for change and a rural community college program emerges (1990's)

The 1980's and 1990's represented an era where technology was becoming increasingly utilized in professional practice and yet engineering education had not evolved far beyond the 1950's [2,3]. This systemic scenario resulted in an emerging international scenario with both an undersupply of engineering graduates and deficiency in the capabilities required of the graduates as engineers. Within the international community, a landmark point in the dialogue commenced in 1989 with what would become known as the Washington Accord with professional organizations and institutions from Australia, Canada, Ireland, New Zealand, United Kingdom, and the United States to establish new standards for professional competencies and graduate attributes. Several countries from around the world would later join the Washington Accord [3].

In 1996, ABET introduced ABET Engineering Criteria 2000, a new set of engineering accreditation criteria with increased focus on student outcomes with General Criterion 3 Student Outcomes (a-k). This required engineering programs to define student outcomes for the attainment of professional skill and competency aspects of engineering. This marked a clear need for programs to shift beyond just technical skill attainment focus for engineering graduates [4].

In addition to the focus on increasing the capabilities of engineering graduates, there was also increasing focus on increasing the number and diversity of engineering graduates to reflect society's demographics [5,6,7,8].

Throughout this dialogue was increasing recognition of the value of community colleges in meeting the nation's needs for engineering graduates. It was clear that if engineering education was going to graduate the number of engineers needed in the U.S., with demographics that reflect the demographics of society, community college engineering programs and pathways were an integral part of the solution.

During this same time era, two community college instructors came together in 1992 to imagine how they might serve a rural region by providing the first two years of engineering education, with a multi-disciplinary emphasis, before students would need to leave the region for completion at a university [9]. The focus on increased access would benefit not only students and their individual opportunities but also regional employers who were struggling to attract and retain adequate numbers of engineers in their rural locations. Most of the region was a multiple hour driving distance from the nearest engineering university. In addition to access was the desire to improve the pedagogy to address dissatisfactions with the low-level of learning in lecture-based courses and the lack of preparedness of undergraduate engineering completers to practice engineering. The dual focus of increased engineering student access and retention along with the drive to improve pedagogy and curricular models would guide the program development for the next three decades.

Program Element: Recruiting

While the original implementations developed learning experiences that led students to graduation and career entry, just as big a part of the story are the strategies developed to attract students to the profession and the programs. In 2003, the community college instructors who started the program published a retrospective paper at an AAAS conference looking back at the problems they encountered with the solutions they implemented [9]. See Figure 1.

The Problem: Lack of effective exposure to STEM careers throughout a student's K-12 education. The ICC Engineering Solution: Use a proven combination of classroom visits, summer programming, and immersion events to increase student exposure to STEM careers. The Result: ICC Engineering has doubled enrollment in the past 5 years and delivered STEM information to dozens of teachers and thousands of K-12 students. (Written in 2003)

Figure 1. Recruiting approach implemented in 1990's [9].

Not stated in the figure is how they were using those strategies to develop social connection. Through spending time in their K-12 classrooms, usually through multiple visits, having them come to the college campus for things like Rube Goldberg and to interact with practicing engineers, and hosting summer engineering camps, the program staff and K-12 students built enough of a relationship that on the first day of college, everyone already knew each other's names and much about them. In the original and follow-on programs, recruiting activities are so essential they could be considered part of the curriculum. In the present day, the activities look quite different, but they still take place in classroom visits and through immersion events and summer programming. They have become more integral to the curriculum while the audience has changed from a few K-12 public schools in the rural region to community colleges across the country.

Regional access was built upon with the creation of strong articulation agreements with an increasing number of institutions, eventually reaching thirteen partner transfer institutions. This meant increasing access to four-year degrees that better aligned with student interest and greater retention as students had choice of degree and campus culture options that met their needs. This value of student autonomy of choice would also guide the program for the next three decades.

Program Element: Learning Communities

One pedagogical strategy "discovered" early on was the importance of student sense of identity and forming as a community of learners with faculty [10,11]. Figure 2. also comes from that 2003 AAAS paper.

The Problem:
Lack of effective retention strategies to reduce attrition of first year and sophomore students in the initial stages of collegiate STEM education.

The ICC Engineering Solution:
Use a proven combination of intensive personal coaching, learning community, and extracurricular activities to increase likelihood of successful graduation in the STEM field.

The Result:
Over 80% of ICC engineering students who start Physics I go on to complete degrees.

Figure 2. Retention approach implemented in 1990's [9].

Upon further review, the intensive personal coaching and extracurricular activities were attributes of the learning community [12]. The instructor role had evolved from lecturer/evaluator to learning facilitator, professional development leader, career/life advisor, and partner in life as extracurricular activities grew in diversity to spring break vacations, basketball leagues, and summer picnicking/camping. These deep relationships emerged between peers as lifelong friendships as relationships developed. What started as physical access to campus space became a vibrant community whose members shared the goal of becoming practicing engineers. As can be seen in Figure 2., persistence to a degree was quite high. Through participation in this community, students learned the importance of inclusion and working together on teams. They developed an identity as emerging engineers with the self-efficacy to achieve their goals. They had traversed from being in a classroom to being a culture. These learning communities are a strategy that evolved into living/learning communities and have been a hallmark program attribute to the present day as the evolved program(s) begin a 4^{th} decade of implementation [13].

Further learning community development led to the construction in 2000 of a new engineering center that incorporated housing, student social gathering space, classrooms, STEM faculty offices together to form a living and learning community with positive change in student success. Soon thereafter, with increased program enrollment growth, a second adjacent residential building was constructed to expand access to the living and learning community.

Throughout this period of growth and increased rural access and student success, the disconnect between student learning and professional practice continued to be an area that needed further focus. This was not only true locally but truly still across the U.S. [1] engineering educational community.

An Awakening in Engineering Education and Curricular Innovation at a Rural Community College (2000's)

Despite the effort of initial call for changes in the 1990's, as the engineering education system entered the 2000's, it still was not changing regarding the professional development needs of the profession, as later identified in Sheppard's Educating Engineers: Designing for the Future of the Field [14]. This resulted in the early 2000's seeing several renewed calls for the long-needed changes in engineering education such as NAE's Engineer 2020 [1] and Educating the Engineer of 2020 [15], Rising above the gathering storm [16], Moving forward to improve engineering education [17], and Higher education in the 21st century: global imperatives, regional challenges, national responsibilities, and emerging opportunities [18].

The 2000's marked an era of curricular innovation for the engineering program. A significant initial milestone was a three-day conference hosted by the college in 2002 with support and encouragement from the National Science Foundation's Division of Undergraduate Education, ICC hosted the three-day Sugar Lake Conference in July 2002 [19]. The conference included 80 representatives from nine regions (Arizona, Florida, Maryland, Virginia, Alabama, Washington, North Dakota/Minnesota/Wyoming, California, and New York), for many it was their first attendance at an engineering education conference. The conference, known as the Sugar Lake Conference, simply focused on how to improve access to, interest in, and the quality of engineering education on a national level. Outcomes of the Sugar Lake Conference [19]:

- Development of vision statements and action plans by each region
- Consensus that a national effort was required for: convening and sharing of effective practices; national policy advocacy; and tracking of engineering pipeline statistics
- Significant agreement of the need for a national approach to engineering degree transfer between community colleges and universities. At the time of the conference, at least one-third of engineering graduates attend two or more colleges while pursuing their engineering degrees, and at many universities over 40 percent of students in colleges of engineering began their education at community colleges.

The 2000's saw increased enrollment and thus an increased number of faculty. A faculty-directed professional and curricular development group was established. Through this development group the program was incorporating the emerging engineering education knowledge [20]. The pedagogy development focus was on the formation of student identity as an engineer and preparation for professional practice. Particular attention was focused on the students successfully completing the high school/college transition and the two-year and four-year program transition. The curricular model that evolved from this development period focused continually on:

- building and maintaining students' aspirations for becoming an engineer,
- development of students as professionals,
- students professionally practicing engineering, and
- students learning to *work and function in a community or organization.*

Program Element: The whole engineer

A new chapter in the development story emerged as the ABET 2000 a-k student outcomes came into being. While the first decade of this story was focused on learning communities leading to career entry, the second decade became focused on developing all aspects of the student engineer. Again, this emerged from dissatisfaction with the status quo and the staff members' own educational experiences. Program instructors began defining the whole engineer in the three domains of technical, professional, and design [21]. In other words, the engineer must be a highly technical person, a highly professional person, and a creative, innovative, design-oriented person (see Figure 3.). The curriculum changed from being composed of technical courses to adding in a sequence of four courses titled Engineering Professionalism and Design (EPD I, II, III, and IV) [13].

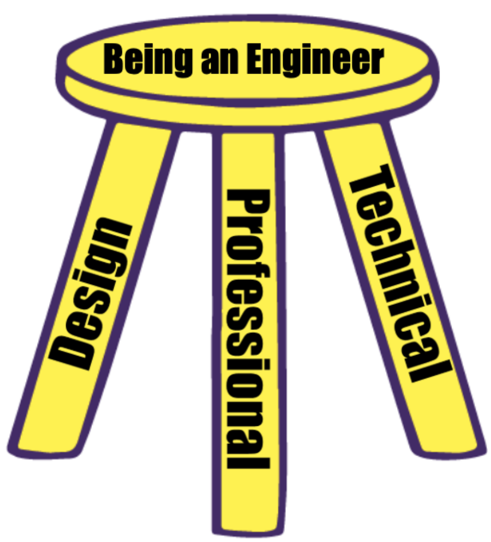

Figure 3. The whole engineer

Using the ABET student outcomes as a backdrop, professional experiences were implemented in the form of workshops and teaming activities. Small, one-semester design projects were implemented in every semester of the two years of lower-division education that were completed at the community college. The multi-disciplinary students began to feel like engineers and their identities were shifting towards being a part of the profession as opposed to just being in training for a profession that they would reach some day. Example strategies that were implemented were ethics conferences, one-day design challenges, service-learning design projects, etiquette training, public speaking, creative performances, and much more. These new activities were layered over the top of the learning community environment and the intensive personal mentoring from staff as well as the extensive set of STEM technical courses. The program grew to a level of national recognition as engineering education leaders from prominent programs came to the rural college to observe the strategies in action, program staff were invited as guest speakers at engineering universities, and the program implemented successful NSF grants related to curriculum and recruiting/retention.

Program Element: Block Scheduling

There are and always have been many structural barriers in the education process to the engineering profession [22]. To overcome one such barrier and to seek improved learning retention, the program implemented a block scheduling system. See Figure 4.

The Problem:
The sequencing of calculus, physics, and engineering transfer courses frequently meant high school graduates would need three years at their community college before transferring to a university for the final two years meaning a four-year degree took five years.

The ICC Engineering Solution:
Turn the four semesters of lower division into 8 half-semester blocks allowing students many opportunities to meet all their sequencing needs in two years instead of three while focusing on learning fewer topics at a time.

The Result:
This strategy, first implemented in 2004, has evolved to be a cornerstone in all three of the different versions of the program today in 2022 with a keen focus on learning transfer as the outcome.

Figure 4. Implementation of Block Scheduling [23]

As an open admissions program, the student body consisted of entrants coming from a wide range of socioeconomic and math preparation factors that can impact their success. 72% of students were first generation college students with 76% qualified for federal financial aid. In math preparation terms, approximately one third of the students were Calculus 1 ready, one third Pre-Calculus ready, and one third below Pre-Calculus in math preparations [24].

With this diverse body of learners and only two years of lower division courses, the model was successful, and it was being nationally recognized, for developing engineers who succeeded in both their upper-division education and their professional practice. Students who started the program finished their engineering bachelor's degree in an average of 8.8 semesters with graduation rates of 49% for all students who start the program and 67% for students who started with or achieved a "calculus 1" math ability [24].

Four key aspects that contributed to the model's success at this point in the evolution were: 1) Strong K-12 relationships, 2) a two-year "across the curriculum" engineering and professional development (EPD) development course sequence (design skills and professional development focus, 3) an active student and faculty learning community, and 4) flexible academic pathways (block scheduling) to allow for different student development and learning opportunities. The entrepreneurial curriculum development of the 2000's aligned with meeting the call of the Engineer 2020 and developing a graduate that truly obtained the ABET Learning Outcomes. Hallmark strategies of this decade were:

- Comprehensive regional recruiting model
- A best practice living and learning community
- Curricular focus on the three-legged stool (technical, professional, and design domains) for the body of knowledge addition in lower division.
- A student learning process that was increasingly incorporating an iterative process and that reflected, what was described by Sheppard [14] as, the *"ideal learning trajectory is a spiral, with all components revisited at increasing levels of sophistication and interconnection. In this networked- model, the traditional analysis, laboratory, and design components would be deeply interrelated: engineering knowledge remains central but is configured to include both technical and contextual knowledge; competencies of practice, laboratory, and design experiences are integrated into the whole, as are professionalism and ethics."*

With a continued focus on expanded access and curricular innovation, this decade of innovation lead to increased recognition of the program's successful curricular elements, yet for the faculty it served to only increase the recognition of the need for expanded innovation in both the direction of upper division curriculum and the direction for expanding the active and application-based learning focus of the curriculum.

National and global changes efforts in engineering education reform and the birth of a new educational model (2010's)

While many efforts were made to change the ways engineering graduates developed professional, design, and technical skills, the 2000's resulted in minimal pedagogical changes for most engineering educational institutions in the United States [25]. While worldwide, many countries were evolving their engineering educational systems.

In response to this dialogue and to continue its curricular innovation and expand student access, and after regional encouragement to develop a local upper-division program grounded in industry projects [26], serious conversations took place between the community college faculty, community members, and national members of engineering academia. In April 2009, a regional organization funded the program's startup [27], at the very same time as the Engineer of the Future 2.0 Summit was held in spring 2009 at Olin College launched Engineer 2.0 [28].

Immediately an advisory board was formed from among the leaders in U.S. engineering education. Sheri Sheppard, Tom Litzinger, Denny Davis, Jeff Froyd, and Edwin Jones began guiding the program's development [20]. Their advice led to the program's change agents visiting Anette Kolmos at Aalborg University [29] and developing an adaptation of the Aalborg model of project-based learning curriculum. In January 2010 [30], a unique, two-year, upper-division, multi-disciplinary, 100% project based learning (PBL) model of engineering education [31] began delivery of the curriculum; an adaptation of the Aalborg PBL model as an innovative collaboration between the rural midwestern community college and a regional university [21].

The implementation of the multidisciplinary curriculum took place on two parallel levels [32]. First, PBL as a curriculum was not widespread and the university systems and mentalities were not well prepared for the abrupt change in educational practices required to implement this PBL model. An NSF sponsored study of the change management activities that occurred during this start-up phase had initial findings that indicated the barriers to change to include credentialing issues, ownership, culture clash, and resistance to change. The empowering factors to change were the "importance of having champions at all levels, creating new boxes for the new program, and having translators positioned at key bridging points" [33].

The second level of implementation was the use of assessment of and feedback from each semester regarding which attributes were working and which were not to directly inform the curricular evolution for the following semester and academic year. This model and mindset of continuous improvement was adopted by the faculty early in the program implementation [30]. Input was sought from current students, industry partners, visiting engineering education experts (at least one group per semester), and academic staff. This continuous improvement strategy has become a hallmark of the programs' evolutions [20].

The results of this implementation process were a smooth and successful ABET accreditation process, elevated levels of ownership in the program by faculty and student groups, low levels of apathy by the faculty and student groups, and a vibrant curriculum that is constantly improving [29, 33]. ABET recognized the program in 2017 with the ABET Innovation Award for "educating their students in innovative ABET-accredited programs that feature trans-disciplinary thinking, industry-sponsored project-based learning, experiential learning in context, competency-based assessments and significant exposure to professionalism, design and creativity" [35]. In 2018, the program was recognized in MIT's The Global State of the Art in Engineering Education" report by Ruth Graham as a top 10 emerging world leader in engineering education [36].

Program Element: Project-Based Learning

In the 2000s, graduates of the two-year program, who had transferred to a regional university for degree completion, started returning with a common message. Their university experience lacked the breadth of professional and design experiences they had in their first two years. The authors of this paper heard this quote or something similar hundreds of times, "the best part of engineering education was at XCC in my EPD classes." Those student messages created a new movement. In parallel with the delivery of the program, staff started dreaming of something bigger – an expansion of their model to a four-year B.S. engineering program.

Development funding was acquired and over a five-year period, a national advisory board was formed, pilot funding was obtained, and a new model was developed. As mentioned above, the new model was inspired by the Aalborg University model of PBL [37] and the learning community, mentoring, professionalism, and design aspects of the community college program. In 2009, the first generation of students began in the Iron Range engineering program. As the community college was not authorized to grant baccalaureate degrees, a partnership was formed with a regional university, Minnesota State University, MSU [30]. The new program became a satellite for the university.

A major curricular shift occurred with the startup of the new program [38]. Design went from being a small, side experience to being a large, central experience, around which all technical, professional, and design learning took place. Several new strategies emerged from the startup evolution, many of which were innovative approaches that intentionally promoted the development of professional, non-technical skills. Figure 5. describes some of these strategies.

Student success strategies
Reflection – in any model of learning developed since Dewey [39], a key phase in the learning cycle is the act of reflecting, or processing of the knowledge. Yet, explicit development or practice of that act is absent in all engineering education. This program put reflection on the front burner and developed hundreds of reflection prompts that became a part of every learning activity, with the goal of graduating reflective practitioners. Through these reflections, student engineers not only processed knowledge, but they developed both a higher sense of self-awareness and increased self-efficacy. Metacognition – Through the reflection experiences and through an explicit metacognition memo twice per semester, students learned what metacognition was and how to practice it. A stated outcome of the program was an advanced ability to manage their own self-directed learning processes, long a desired attribute by industry in new engineering graduates. Studies by Marra, Plumb, and Hacker demonstrated the metacognitive growth of students in the program [40]. Teamwork – With the execution of a design project at the center of the curriculum, came a focus on developing skills needed to thrive in a teaming environment. Most students entered the program with more than a decade of being on school related teams that were dysfunctional with ineffective members who were “passengers” and others who hoarded the work so that they could achieve their desired grade without being dragged down by teammates. Breaking those ineffective habits was central to the goals of the project facilitators. Two strategies of note were to enforce the “rule of 1/x” (if there were 4 people on the team, then each member would do $1/4^{th}$ of the work, etc.) and the process of having practicing engineers from industry as the facilitator for the project, guiding the development of teaming skills. Several reflections mentioned above focus on the development of teaming attributes. One strategy for effective teaming learned from Aalborg University was the concept of “team rooms,” a dedicated space with near 24/7 access for the team to work on and manage their projects [41].

Industry – A desired outcome of the PBL experience from the beginning was the development of an identity of "being an engineer" as opposed to being a student who will someday become an engineer. It was believed by program staff that this identity increased motivation to learn and resulted in increased engagement in the projects as well as all other parts of the education. To achieve this identity, real projects were sought from industry. Professors did not manipulate or simplify the projects. Instead, they were ill-defined and complex. While more challenging, student engineers found them more authentic. It was this authenticity that program staff observed lead to the identity/engagement [38].

Figure 5. Description of select strategies

Beyond student success strategies, a vital program success attribute was the implementation of a culture of continuous improvement [42]. In a profession built on the foundation of continuous improvement of products and processes, having a program built on the same foundation and embraced by staff and students resulted in less opposition to change and a greater backdrop for innovation. From the beginning, a structured process at the end of each semester collected input from internal and external stakeholders to identify potential program improvements. The goal was to achieve improvement through changing ~15% of the learning activities each semester. This continued growth was highlighted as the program gained national and international recognition [34, 35].

The curricular innovation continues with another new curricular model that takes inspiration from the PBL program [21] and another model from the report with Charles Sturt University [43]. It focuses on work-based learning with the industry inspired projects not being completed in an academic setting but being part of a student co-op experience.

Program Element: Work-based Learning

As students progressed through the four-semester, upper-division, project-based learning program, some of them were offered the opportunity to substitute an industry co-op experience in place of their on-campus project. Program staff noticed that the level of identity building, and engagement was even higher for these student engineers than for the PBL students. Staff developed learning activities and created access that enabled a co-op student to both work full-time for their company and meet the requirements to complete a full semester of coursework across the technical, professional, and design domains. In 2016, program staff met the professors leading the startup of the Charles Sturt University (CSU - Australia) engineering program [43] which was a fully work-based learning program.

This chance meeting created a shift in the future directions of the program. Combining the decades of strategies that had already been developed with a new structural model inspired by CSU, a new pilot program was conceived. The new model, running in parallel with the original PBL model, started in August 2019. In this new pilot, lower division was completed at a community college anywhere in the U.S. This was followed by a one semester "boot-camp" called the Bell Academy. During this on-ground semester, student engineers acquired the technical, professional, and design skills they would need to thrive in a co-op as well as the job-search skills needed to acquire the co-ops [44]. After the one semester, students would spend 24 months doing full-time co-op work paired with 10-12 hours per week continuing their technical, professional, and design learning [45].

The intended goals of this new program were to provide an engineering-work-ready graduate, serve the community college student population, provide a more fiscally sustainable education opportunity for students, and take advantage of the many strategies developed in the other iterations of the program which only served a small, rural population [46].

The first student cohort graduated in December 2021. The completers reported elevated levels of satisfaction with the experience, elevated levels of work readiness, and success in achieving co-ops that paid an average of $23/hour for 40 hours per week.

Presidential Perspective

[To this point, the development story in parallel with movements in engineering education has been written by the academics who were in the programs and focused internally on the development. In this section we bring in the perspective of the community college president who takes a more external approach.]

As noted above, elevated levels of student success outcomes and demonstrated workplace readiness in the ICC/IRE engineering programs result from creative and unique pedagogical transformations over several years. These metrics along with the nontraditional approaches to teaching and learning set the programs apart from others across the country [45]. While the instructional pedagogy stands out, an often-overlooked unique attribute of these programs is their rural setting. Located on the campuses of a small rural community college in cities of less than 10,000 residents, the closest four-year campus constitutes a 90-minute commute, and the nearest urban area is 200 miles south.

It would be easy to surmise that placing ABET accredited, world-renowned engineering programs in such a remote setting would put students and the program at a disadvantage. I have found the opposite to be true. Like most rural areas, our region is hungry for place-based educational opportunities, and consequently, our engineering programs receive inordinate support to ensure quality and sustainability. This support is justified because the impact to the Iron Range area is significant. The ICC/IRE engineering programs create multiple advantages for our region that I believe would not be realized in an urban area saturated with higher education opportunities. As the only program of its kind in our rural setting, people take notice.

Our two-year campuses benefit from increased visibility, place-based transfer options for students, and a more vibrant collegial atmosphere. Local legislators recognize the positive economic impact of bringing students to the region for 4 years of school and potential future employment and attracting well-compensated faculty and their families to the Iron Range. They have responded with significant support including scholarship dollars, operating funds, and capital bonding for facilities improvements on our two-year campuses.

Regional industry partners understand the value of the learner/worker model and support students throughout their education with project-based learning, scholarships, and job prospects. A high percentage of students stay in the region and are often employed by the company they partnered with as students, which is extremely effective in combating rural brain drain. We have been able to keep forward-thinking, young professionals in our communities who help rebuild the cross-generational social fabric of the region.

While ICC/IRE engineering is intentionally embedded into a learning community design, the rural setting and relative isolation of our region creates a naturally expanded learning community not likely found in an urban or large university setting. Faculty, students, community leaders, and industry partners are also neighbors, friends and relatives who support each other inside and outside of the classroom. Unquestionably, the creators and faculty of ICC/IRE engineering have built a universally recognized program with innovative pedagogy that has led to enviable student success outcomes. Less recognized are the observable benefits to the program and students because of the rural setting. As the old adage says, "It takes a village," and I have observed our "village" step up big in contributing to the success metrics of ICC/IRE engineering.

2020's: Future

In September 2021, in Issues in Science and Technology, three of the premier leaders of engineering education called for a "sea change" in the field of educating engineers. Sherly Sorby, Norman Fortenberry, and Gary Bertoline made the bold statement: "Stuck in 1955, Engineering Education Needs a Revolution. [21]"

"This transformation must begin with a deliberate effort to build an inclusive and collaborative engineering community that spans disciplines, gender, ethnicity, race, and sexual orientation. To do that we have to reassess the content and nature of both precollege outreach and undergraduate education to build interest in and preparation for the study of engineering. In step with this assessment of the curriculum and outreach efforts, we must also evaluate our expectations of engineering faculty and reimagine the structure of how we train engineers [21]."

They are saying we need to overcome the structural barriers to entry of the profession by revolutionizing the undergraduate education experience. The revolution will need to encompass not only the lived experience, but also the content. With the emergence of Industry 4.0 what new engineers need to know is different than in the past and what they need to be able to do is changing just as rapidly. We must be nimble enough to quickly change content with the changing landscape and we need to focus more on problem solving processes. We need to be "assigning messy problems that would require the synthesis of concepts from multiple disciplines, applying logical boundary conditions, and examining outcomes to make sure they are reasonable, [instead of] assign[ing] problems that could be solved with a slide rule. [21]"

Using this call as a mandate, the programs described in this paper have begun to look to the future as an opportunity. Having evolved, as Ruth Graham recently said about us [42], with continuous improvement as a part of our DNA, we must continually look inward to eliminate barriers to access and portray outwardly to our future students the lived culture of inclusion, equity, and collaboration. Our focus on creative, innovative, open-ended problem solving must continue to mature and produce graduates ready for tackling messy, complex problems through systems approaches integrating all disciplines. We see these challenges as achievable within our program structures. More difficult is to overcome archaic curriculum approval systems in colleges and universities that inhibit meeting the rapid need for content change. We will continue to advocate for improvements in these systems to allow content needing changes to keep pace with the engineering landscape.

Summary of Timeline, Lessons Learned, & Suggestions for Others

Timeline

To help the reader to visualize the program development, Figure 6 provides a summary graphic of the timeline for both the broader engineering education community and program element development for a rural engineering education institution.

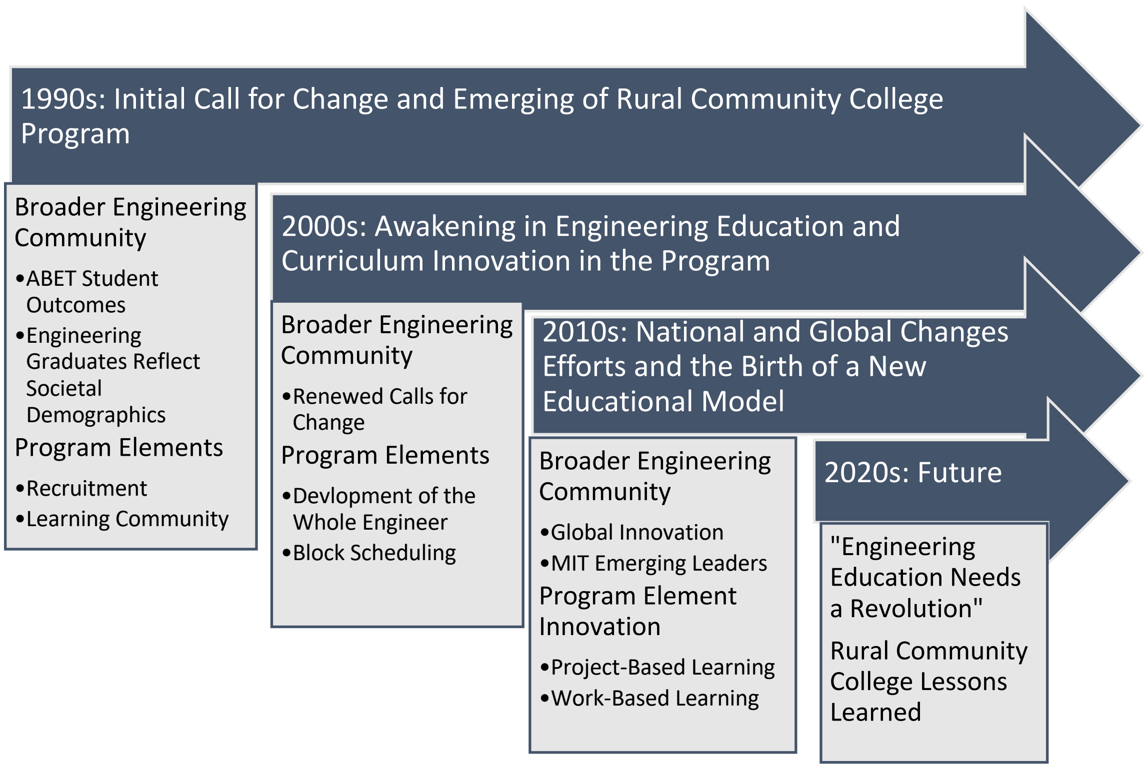

Figure 6: Engineering Education Timeline

Lessons Learned

Over the four decades, patterns emerged with respect both to obstacles that would need to be navigated for each iteration and those that could be avoided by implementing past experiences.

A continually faced barrier comes from the resistance to change in an organization. Structural barriers exist in systems. An example would be when block scheduling was implemented; the registration system, transcript system, and personnel in the registrar's office were not ready for such a change. Another example would be the implementation of PBL where the technical courses were put into 1-credit modules. The curriculum approval process was structured such that this change was resisted and difficult.

Peoples' reactions are also an obstacle that is ever present when innovative programs are being proposed and implemented. Some faculty members seeing something different feel a challenge to their identity. This is seen quite frequently when implementing active learning methods, especially for the people whose identity was tied to being a lecturer and had strong beliefs that it was the superior model. At many points in the curricular innovation process, there were sometimes people in the department who were unwilling to try the new strategies, and there were those in other departments who put up barriers through the college's curriculum approval processes.

Another human interaction to expect comes from the emotional reaction by students. Many have developed a personally efficient algorithm for course success. When a new model of learning disrupts that algorithm, some students put up substantial resistance as their algorithm is challenged. There is also a phenomenon observed in the "pioneering cohorts." When the first PBL model was implemented, the students and faculty were embarking on a significantly new path. Everything looked different than their past experiences. When difficulties arose, rather than accept them as new challenges, a common reaction was to blame the new model. Often, students were certain that they were experts, and the faculty did not know what they were doing. This resulted in a resistance that impeded finding good solutions.

An example of a lesson learned by one implementation that was avoided in the next new program was also related to the pioneering cohort. During the PBL implementation, the first generation of students who took on some negative approaches to their situation had a long-lasting negative influence on subsequent new cohorts due to them all being enrolled in the program and learning in physical proximity to one another. With this lesson learned, for the WBL (Work Based Learning) implementation, new cohorts underwent their training semester physically dislocated from their peers in previous cohorts. This resulted in a much smoother and more rapid implementation of change processes.

Suggestions for Others

Developing new programs and implementing emerging learning pedagogies is challenging. The cognitive and emotional demands are high. However, the rewards are most often worth it. Engineers embrace failure along the pathway of continuous improvement. The improvements in learning models result in a more transformative experience for student engineers. This modeling of the engineering design process for the student participants brings them value. The communities that emerge are strong. The relationships between the innovators, both faculty and students, are strong and long lasting.

People considering implementing changes in the form of innovative programs should visit as many exemplary programs as possible. This was a strategy used at every juncture described above. The knowledge from those visits came in the form of strategies that could be adapted in the new model and advice from the implementers that proved highly valuable.

Details of Curricular Innovations

The power of the IRE model of engineering education comes from not just the real, complex, industry-driven design projects but also from the unique components that help students frame and conceptualize their own learning as they prepare to move from learning in a formal academic space to a lifetime of learning as engineering leaders. The following unique elements, all of which are required in the student experience, are adaptable and transferable in most engineering programs.

DLA (Deep Learning Activities): Help students achieve depth of understanding around a topic of relevance to the project or of special interest to the student. Deep learning activities include such things as developing a mathematical model for the team's project and then developing and conducting an experiment that provides data for the project. The goal of the deep learning activity requirement is to connect the engineering theory learned in technical competencies to real life examples and to provide a hands-on learning experience related to the competency.

Learning Journal: Metacognitive learning happens through students planning their learning, organizing, and reorganizing their factual and conceptual knowledge, reflection, evaluation of their learning, and using the reflections and evaluation to dictate future learning. Each student keeps a learning journal for every competency in which they record this planning and organization and write the reflections and judgments. At the end of each block, students write a metacognitive memo analyzing their learning during the four competencies and making future learning goals.

CIOPS (Creative, innovative, open-ended problem-solving): Students participate in workshop activities to develop CIOPS skills. Once every semester, students are given an open-ended problem with a limited amount of solution time (less than 24 hours). They must do research, engineering analysis, create a solution, and present that solution to a panel. The panel then gives the student feedback about their open-ended problem-solving techniques. Students reflect on the results to improve their approaches the next time they are challenged with an open-ended problem.

IRE Talks: These are like TED talks. Students create a presentation on a current event or topic they are passionate about and then present it in a theater to an audience of their peers and faculty. They receive feedback on their presentation skills as well as the strength of the engineering connections they make to their topics.

Jobs Package: Students find a job they would like to apply for and create cover letters and resumes. They then go through a series of phone interviews and live mock interviews, culminating in attendance at the IRE career fair. They receive feedback from faculty and peers every step of the way and craft their ability to articulate both their learning and their vision of their future careers.

Communication: After a student has graduated from IRE, they will have given approximately 50 presentations (everything from their IRE Talks to project updates to verbal technical exams). They will have also written hundreds of technical documents that include research papers, experiment design reports, design memos to clients, and reflections as part of the deep learning activities for classes as well as 100+ page technical reports each semester that describe their project work. Each of these receives feedback from either faculty, peers, or a technical communications expert. Communicating engineering knowledge in multiple ways to multiple audiences is reinforced.

Self-Directed Learning: A key programmatic outcome is developing life-long learning skills. In industry, knowing how to find information is crucial to being a successful engineer. Knowing what is unknown and identifying how to find it is crucial to self-directed learning. Students learn about learning processes, mentorship mapping, reflection, metacognition, and time management to help them with this effort. As with everything else, students get feedback on their processes and suggestions for improving them.

Grading scale: The program created its own grading scale from 0-5. What makes the scale unique is that a score of 5 is a rarely seen "unicorn." This helps the community embrace a feeling that no matter how well they have performed, there would still be room for further improvement. This aspect of the culture creates recognition that excellence is a journey as opposed to a destination. Further, this creates collaboration as the norm with elimination of a sense that "for me to succeed, I need to do better than you."

Oral examinations: A defense of learning used to evaluate a student's achievement of technical competencies. At the end of a block, each student must defend his or her knowledge for each technical competency before a faculty or instructor evaluator. The examination lasts up to an hour and covers an appropriate set of basic topics, student-chosen areas of emphasis, and the deeper learning activity conducted for the competency. The score awarded for an oral examination indicates the student's overall breadth and depth of knowledge for competency.

Design documentation: Technical reports are used to evaluate students' achievements in their design projects. Upon completion of their project, a team submits a technical report documenting the entire design process and their design solution. The team also creates and delivers an hour-long presentation on their project directed at fellow students and project clients. The written and oral reports provide evidence from which faculty can judge the team's design achievements. Feedback from faculty and members of the audience also provide students information for creating or updating students' individual development plans.

Personnel Evaluation: The culmination of the student's professional experience for the semester is a personnel evaluation like one that would be administered by an engineer's supervisor in industry. The project mentor and the student fill out the evaluation independently then meet for a frank discussion on strengths, weaknesses, and goals for improvement. This activity serves as the catalyst for the student's end of semester Professional Development Plan where they address their leadership and professional experiences and growth during the previous semester, current levels of professional skill along the continuum from novice to expert in the many professional domains, and goals and implementation plans for growth in the upcoming semester (or year in the case of graduating seniors).

Figure 7. Example curricular elements for adaptation by others

Conclusion

This parallel review of engineering education and a particular program's evolution provides value to the broader engineering education community in the recognition that we are all on a continuum of continuous improvement in engineering education. One value of this paper to the broader engineering education community is in the pedagogical and curricular models that have developed through the program's evolution, which serve for consideration and potential adaptation to provide what engineering education needs as the profession revolutionizes and evolves to meet societal needs.

However, it is not enough to just look at the changes and evolution that has occurred in this program and in engineering education; the process of the change itself must be acknowledged. Goldberg and Sommerville in *A Whole New Engineer: The Coming Revolution in Engineering Education* [47] identify that *"restructuring curriculum and reforming pedagogy" are not enough in themselves. It requires a cultural shift, a movement of both colleagues and students "building community, by showing people the new world, by using language intentionally, by using structures intentionally, and by being open to change course. In doing this we begin the process of shifting culture to one that is trusting, joyful, collaborative, open, and courageous. And, thus, we begin to enable the creation of the Whole New Engineer."*

Throughout the three-decade evolutionary process and now moving into the fourth, the faculty built an entrepreneurial spirit and changed culture with students, administration, and the community, that maintained the dual focus of increased student access and continuous improvement as a programmatic strategy that has become embedded in the learning models. While pedagogical improvements were intentional, most powerful was the educational environment strategy that emerged in the form of learning communities and colleagues embracing a culture of change. Strong social connections were built between faculty/students and student/student. Informal gathering spaces accessed from early morning to late night became the backdrop for the relationship building. A culture of trust, joy, collaboration, openness, and courage emerged with a common set of professional goals. In the end, this is the most important program element needed as we, engineering educators, develop educational experiences to develop engineers that will meet the needs of society, now and into the future.

References

[1] National Academy of Engineering, "The Engineer of 2020," The National Academies Press, Washington D.C., 2004.

[2] D. Beanland and R. Hadgraft, *UNESCO Report, ENGINEERING: Issues, Challenges, and Opportunities for Development,* Melbourne, Australia: RMIT University Press, 2011

[3] D. Beanland and R. Hadgraft, *UNESCO Report, Engineering Education: Transformation and Innovation,* Melbourne, Australia: RMIT University Press, 2013

[4] R.S. Adams and R.M. Felder, "Reframing Professional Development: A Systems Approach to Preparing Engineering Educators to Educate Tomorrow's Engineers", Journal of Engineering Education, 97(3), 239-240, 2008.

[5] U.S. Department of Defense, "Roadmap for National Security: Imperative for Change. Phase III Report of the U.S. Commission on National Security/21st Century", U.S. Government Printing Office, Washington, D.C., 2001.

[6] National Academy of Engineering, “Enhancing the Community College Pathway to Engineering Careers,” The National Academies Press, Washington, D.C., 2005.

[7] S. Tobias, “They're not dumb. They're different.: A new “tier of talent” for science,” *Change: The Magazine of Higher Learning*, vol. 22(4), pp. 11-30, 1990.

[8] R. Felder, "Reaching the Second Tier: Learning and Teaching Styles in College Science Education." Journal of College Science Teaching, vol. 23(5), pp. 286-290, 1993.

[9] R. Ulseth, "From nothing to something", in *AAAS*, Washington DC, 2003. Available: https://www.aaas.org/sites/default/files/03_Suc_Peds_Ulseth.pdf. [Accessed: 03- Feb- 2022].

[10] V. Tinto, “Learning Communities and the Reconstruction of Remedial Education in Higher Education,” in *Conference on Replacing Remediation in Higher Education sponsored by the National Center for Postsecondary Improvement and the Ford Foundation*, January 26-27, 1998.

[11] J. Braxton, R. Johnson, and A. Shaw-Sullivan, “Appraising Tinto’s theory of college student departure,” in Higher Education: Handbook of Theory and Research, Volume 12, pp. 107-164, New York: Agathon Press, 1997.

[12] B. Johnson and R. Ulseth, G. Savela, M. Hansen, and J. Kennedy, "The Itasca CC Engineering Learning Community", in *ASEE Annual Conference and Exposition*, Vancouver, B.C., Canada, June 26-29, 2011.

[13] B. Johnson, "Study of Professional Competency Development in a Project-Based Learning (PBL) Curriculum.", PhD, Aalborg University, DK, 2016.

[14] S. Sheppard, K. Macatangay, A. Colby, & W. Sullivan, E*ducating engineers: Designing for the Future of the Field.* San Francisco, CA: Jossey-Bass, 2009.

[15] National Academy of Engineering, “Educating the Engineer of 2020”. The National Academies Press, Washington D.C., 2005.

[16] National Academy of Sciences, National Academy of Engineering, and Institute of Medicine, “Rising Above the Gathering Storm: Energizing and Employing America for a Brighter Economic Future, The National Academies Press, Washington D.C., 2007.

[17] S. Beering, “Moving forward to improve engineering education,” National Science Foundation, Arlington, VA, 2007.

[18] J. Duderstadt, “Higher education in the 21st century: Global imperatives, regional challenges, national responsibilities, and emerging opportunities” *The globalization of Higher Education*, 195-206, 2007.

[19] E. Fielding, “The Sugar Lake Conference: Creating National Collaboration in Engineering Education”, conference report, Grand Rapids, MN, 2003.

[20] National Research Council, *How people learn: Bridging Research and Practice,* National Academies Press, Washington, D.C., 1999.

[21] R. Ulseth, "Self-directed learning in PBL", Ph.D., Aalborg University, DK, 2016.

[22] S. Sorby, N. Fortenberry and G. Bertoline, "Stuck in 1955, Engineering Education Needs a Revolution", *Issues in Science and Technology*, September 13, 2021.

[23] B. Johnson, R. Ulseth, G. Hodgson, and E. Damiani, “Itasca CC Engineering Block Scheduling Model”, in *ASEE Annual Conference and Exposition*, Vancouver, 2011.

[24] B. Johnson, R. Ulseth, G. Savela, M. Hansen, and J. Kennedy, “The Itasca CC Engineering Learning Community”, in ASEE Annual Conference and Exposition, Vancouver, 2011.

[25] S. Singer and K. Smith, "Discipline-based education research: Understanding and improving learning in undergraduate science and engineering," *Journal of Engineering Education,* vol. 102(4), pp. 468-471, 2013.

[26] R. Ulseth and B. Johnson, "Iron Range Engineering PBL Experience ," *Proceedings of Seventh International Symposium on Project Approaches in Engineering Education,* July 6-9, 2015, San Sebastian, Spain, School of Engineering of University of Minho, Guimarães, Portugal, 2015

[27] J. Cole, "No one does engineering like the range", Hometown Focus, 2012.

[28] R. Miller, *Rethinking Engineering Education for the 21st Century,* Symposium on Engineering and Liberal Education Union College, Schenectady, NY, June 4-5, 2010

[29] R. Ulseth, D. Ewert, and B. Johnson, "Work in progress—Implementation of a project-based learning curriculum", In 2011 Frontiers in Education Conference (FIE) (pp. F1F-1), IEEE, Rapid City, SD, 2011.

[30] R. Ulseth, J. Froyd, T. Litzinger, D. Ewert and B. Johnson, "A new model of project-based learning", in *ASEE Annual Conference and Exposition*, Vancouver, 2011.

[31] R. Ulseth and B. Johnson, "100% PBL curriculum: startup phase complete", in *Frontiers in Education*, Madrid, 2014.

[32] B. Johnson and R. Ulseth, "Professional Competency Development in PBL", in 5th International Research Symposium on PBL. San Sebastian, Spain, July 2015.

[33] C. Allendoerfer, R. Bates, J. Karlin, R. Ulseth, and D. Ewert, "Leading large-scale change in an engineering program", in *ASEE Annual Conference and Exposition*, Seattle, 2015.

[34] R. Bates, and R. Ulseth, Keynote: RosEvaluation conference, Rose-Hulman, 2013.

[35] ABET, "ABET Innovation Award | ABET", *Abet.org*, 2017. [Online]. Available: https://www.abet.org/awards/abet-innovation-award/. [Accessed: 03- Feb- 2022].

[36] R. Graham, "The global state of the art in engineering education", Massachusetts Institute of Technology, Bost Massachusetts, 2018.

[37] A. Kolmos, L. Krogh and F. Fink, *The Aalborg PBL model*. Aalborg: Aalborg University Press, 2007.

[38] R. Marra, B. Palmer, R. Ulseth and B. Johnson, "The Iron Range Engineering PBL curriculum: How students adapt and function in PBL", in *ASEE Annual Conference and Exposition*, Vancouver, 2011.

[39] J. Dewey, *How we think*. Courier Corporation, 1997.

[40] R. Marra, D. Hacker and C. Plumb, "Metacognition and the development of self-directed learning in a problem-based engineering curriculum", *Journal of Engineering Education*, vol. 111, no. 1, pp. 137-161, 2021. Available: 10.1002/jee.20437.

[41] A. Kolmos, P. Bogelund and C. Spliid, "Learning and Assessing Problem-Based Learning at Aalborg University", in *The Wiley Handbook of Problem Based Learning*, 1st ed., M. Moallem, W. Hung and N. Dabbagh, Ed. Hoboken, NJ: John Wiley and Sons, 2019.

[42] R. Graham, "Engineering Education: Resilience and Purposeful Change", *Advances in Engineering Education*, vol. 9, no. 3, 2021. Available: https://advances.asee.org/engineering-education-resiliance-and-purposeful-change/. [Accessed 3 February 2022].

[43] E. Lindsay and J. Morgan, "The CSU engineering model: educating student engineers through PBL, WPL and an online, on demand curriculum", *European Journal of Engineering Education*, vol. 46, no. 5, pp. 637-661, 2021. Available: 10.1080/03043797.2021.1922360 [Accessed 3 February 2022].

[44] B. Johnson, R. Ulseth and Y. Wang, "Applying design-based research to new work-integrated PBL model (The Iron Range Engineering Bell Program)", in *IRSPBL 2018*, Beijing, China, 2018.

[45] R. Ulseth, B. Johnson and C. Kennedy, "Iron Range Engineering", *Advances in Engineering Education*, vol. 9, no. 3, 2021. Available: https://advances.asee.org/iron-range-engineering/. [Accessed 3 February 2022].

[46] J. Karlin, C. Mann and R. Ulseth, "Just Deserts: Engineering for All, Everywhere", in *Frontiers in Education*, Covington, Kentucky, 2019.

[47] D. Goldberg and M. Somerville, and C. Whitney, *A whole new engineer. The coming revolution in Engineering Education,* Douglas, MI: ThreeJoy Associates Inc., 2014.