Developing an Interdisciplinary Pathway for Engineering Education Master's Curriculum

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***Abstract*—In this Work-in-Progress (WIP) paper, we share how we address the urgent need to prepare Science, Technology, Engineering, and Mathematics (STEM) teachers and faculty with 21st-century teaching and learning knowledge and skills. Engineering education is now provided across all levels of learning and yet a major constraint is the number of teachers and informal educators prepared to teach engineering content. While engineering higher education faculty are likely in possession of strong discipline-specific knowledge, they often enter the workforce without formal pedagogical training. Faculty may be lacking guidance on how to develop best-practice approaches for pedagogical content knowledge or how to effectively teach students literacy within a discipline.**

Across our nation's educational landscape, engineering education graduate programs housed in engineering and education schools are striving to meet this ongoing demand for more and qualified engineering educators. At our university, we are looking to enter this market and develop a master's level program in engineering education focusing on providing discipline-specific, evidence-based pedagogy to students with engineering backgrounds and students with education backgrounds. This work, based on current gathered data and perspectives, raises fundamental questions about audience, purpose, and transformative approaches.

Keywords—engineering curriculum, STEM, graduate education, educational development

I. Introduction

We live in a scientific world impacted daily by technology and engineering. Yet, far too often, as the demand for STEM-related jobs increases and the need to develop STEM literacy rises, our country's ability to meet these needs is failing to keep pace. Science and math, as traditional subjects, have support within educational institutions and pedagogical practices have been firmly established. However, while the discipline of engineering education has seen a dramatic rise in research and scholarly activity, preparing and training a sufficient number of engineering educators remains challenging.

When it comes to engineering education, how can we create multiple pathways to produce effective engineering educators? Across our nation, numerous institutions, agencies, and graduate programs are addressing these pathways by offering master's programs, certificates, endorsements as well as micro-credentialing. Regardless, it remains a concern that many engineering educators possess either pedagogical or subject-matter specific knowledge, but rarely both. Thus, more educational opportunities are needed to address these deficiencies.

At a large, land-grant university in the Mid-Atlantic United States, we are investigating how to prepare engineering students for a pedagogical-focused career—whether that be in a secondary school setting, in an informal setting such as a museum, or an institution of higher education. Likewise, we recognize our capabilities to provide engineering-specific, evidence-based pedagogy to educators. This paper seeks to explain the challenges of both training engineers to be educators and preparing educators to teach engineering. We are optimistic that if we can successfully create educational programs that lead to improved pedagogical practices in the teaching of engineering, then a wider view of engineering will be presented to students. Doing so will open the umbrella of STEM and result in a more inclusive and diverse engineering profession along with a better-informed citizenry needed in today's complex techno-society. Furthermore, creating an additional formalized pathway into education from engineering will work to retain a more diverse set of engineering professionals in the field.

In this paper, we provide a review of existing engineering education programs and identify gaps. Next, it describes our analysis of potential students, scope, instructional pathways, and

collaborations. We then present challenges and opportunities of working across two different fields – engineering and education. Engaging both groups also presents the opportunity to enhance high school-to-college pathways for engineering students. The paper will conclude with a discussion of what we have learned and the next steps.

II. BACKGROUND

A. Existing Programs

We began by benchmarking engineering education programs and found a broad range of offerings in master's degrees and certificate programs related to engineering education [1]. Many of the programs focus on engineering education issues such as disciplinary-specific teaching methods, scholarly inquiry, assessment methodology, and educational leadership practices. The target audience for these programs includes all levels of instructors in primary, secondary, and higher education institutions and are often specifically designed to meet the needs of working teaching professionals and those who instruct in non-academic settings.

Given that we are exploring graduate educational opportunities at the master's level, we focused on degree offerings that vary from Master of Engineering Education, Master of Science in Engineering, and Master of Engineering and Technology Education depending on the focus of the plans of study. In addition to degree options, many programs offer certificates and other credentials. Our review looked specifically at programs and offerings housed in a college or school of engineering and found these typically listed as Engineering Education. Although we fully recognize that engineering education is multidisciplinary, our interest was to see how other engineering programs are providing curriculum developed by and for engineering educators. Studying existing programs illuminated what works and where there is greater need; there is a limited number of programs preparing engineering faculty and teachers with the skills and knowledge to teach using evidence-based, student-centered pedagogies.

B. Trends in Engineering Education

The world is changing almost faster than people can adapt. Engineers are facing problems and assuming responsibilities they may not be explicitly prepared to face. Some suggest that the rate of change of content in the engineering course of study may not be doing enough to prepare engineering students for their entry into the workforce [2]. Revolutions in technology dictate a need for effective dissemination of its use and practices. To keep up with advances in technology, so too must the field of technology and engineering education. Just as industrial revolutions can be grouped into four eras, the history of related technology/engineering educations can be grouped into a similar group of four. At the time of this paper, we are several years deep into "Industry 4.0" [3] and similarly, in the era of engineering education 4.0. Thus, prudent actors in the engineering education arena have a duty to prepare for the industrial revolution 5.0 and the related engineering education revolution 5.0 [2].

Technology makes the world increasingly cosmopolitan and as such, technology makes the accumulation, analysis, and communication of information increasingly successful. Siloing of expertise is becoming less commonplace as the need for engineers with more diverse skillsets is desired. Knowledge domains will inevitably overlap, as new scenarios will manifest in the emerging educational landscape. Engineers of tomorrow will need to be increasingly innovative, flexible, culturally conscious, ethical, and globally aware. One of the challenges then will be for engineering education programs to effectively operationalize scientific findings for use in the curriculum. Institutions that support educator training should, likewise, prepare for such courses of study. Preparing for Engineering Education 5.0 will occur at various levels.

Pre-college engineering education is also responding to what is happening in our engineered world. A new report, Framework of P-12 Engineering Learning, offers a guide to develop programs and learning experiences to enable students to: "(1) orient their ways of thinking by developing Engineering Habits of Mind, (2) be able to competently enact the Engineering Practices, and (3) appreciate, acquire, and apply, when appropriate, Engineering Knowledge to confront and solve the problems that they encounter [4]. No longer is it good enough to teach our youth that engineering is a vehicle for science education, but instead, we need to be capable of including it in every child's formal education.

III. OPTIMIZING STUDENT SUCCESS

Preparing teachers and faculty to enter today's classrooms that demand higher levels of expertise and instruction is an issue facing all levels of engineering educators. This need, an ongoing issue, has been raised for years. For example, in a 2005 ASEE Conference paper, the authors noted, "Recent years have seen awareness of the lack of training of the majority of engineering faculty in topics involving human learning, appropriate pedagogical approaches for engineering topics, and design, implementation, and evaluation of curricula" [5]. In our nation's K-12 schools, teachers are educated on how to teach, but there are shortages of qualified teachers with engineering disciplinary knowledge. Engineering faculty are well versed in disciplinary knowledge, yet most have never formally been schooled in pedagogy [6]. Engineering educators at all levels should seek to develop evidence-based teaching practices that maximize student motivation, student learning, and positive learning experiences.

Not only is there a need for enhancing pedagogical skills and promoting the use of student-centered strategies, but educators need to address the needs of their diverse student populations. In STEM higher education classes, students are mostly taught via passive lectures [7]. Yet there is evidence that underrepresented students benefit from active learning techniques (e.g., group work, think-pair-share, problem-solving) in their STEM classes [8]. Although active learning is any instructional method that engages students, it actually goes beyond engagement and requires students to perform meaningful learning activities and think about what they are doing [9]. In schools and institutions of higher education, students are increasingly culturally and linguistically diverse which results in more recognition for the need to teach inclusively. "Teaching inclusively means embracing student diversity in all forms—race, ethnicity, gender, disability, socioeconomic background, ideology, even

personality traits like introversion—as an asset"[10]. By recognizing that traditional pedagogical methods are not advancing all students, our group is reviewing and promoting evidence-based inclusive learning and teaching strategies [11] to be taught and promoted in our engineering education pathways.

IV. SWOT ANALYSIS

A SWOT (Strengths, Weaknesses, Opportunities, and Threats) analysis is a common business framework for project assessment and decision-making. Our group created a SWOT analysis for the ongoing development of the master's in engineering education program described in this paper. One of our primary strengths in the development of this program is the positioning of our institution. Due to our distributed campus arrangement, we have diversity in backgrounds of engineering faculty, with some individuals possessing experience in secondary education in addition to higher education. Our status as a state-affiliated university also provides us with connections to government agencies responsible for the secondary education system and provides a basis for a working relationship. There is a nationwide need for engineering educators at all levels. Creating a program whose focus could help bridge the gap between secondary engineering education and higher education represents a significant opportunity. These potential strengths, however, may also bear challenges, in that the firm definition of the program's focus, organization, and administrative management has been somewhat difficult to finalize. Our program could also be limited by our institution's cost of tuition, and the need to sufficiently differentiate and market the program to prospective students such that we can meet enrollment targets. The results of our SWOT analysis are summarized in Table I and will be used as a reference in future program planning.

TABLE I. SWOT ANALYSIS

Strengths	**Weaknesses**
• Engineering faculty across multiple campuses • Expertise in STEM secondary education, higher ed engineering education, engineering, and research • Varied backgrounds in teaching and education • Connections, relationship, and support with State Department of Education (DOE)	• Market basis, delivery mode are currently moving targets • Uncertainty about support and interest in project from other university departments • Unresolved interdisciplinary issues • Existing courses program might utilize come from many various departments
Opportunities	**Threats**
• Growing national need for engineering educators • Provide innovative and unique engineering education viewpoint • Build upon existing faculty expertise in engineering ed • Facilitate participation between secondary and university-level engineering educators	• Potentially high price tag for attending our institution • Ability to meet enrollment expectations • Support and resources needed to design and develop engineering education offerings • Existing competitors and ability to differentiate this program

V. IDENTIFICATION OF NEEDS

A. Survey Results

A brief online survey consisting of 10 questions (demographics, scaled responses, and open-ended) was sent to roughly 70 engineering faculty. By including three open-ended questions asking respondents to define engineering education, list student candidate populations for our engineering education programs, and suggest how our university can contribute to engineering education, we gained some insights on how our faculty perceive engineering education. Of the forty responses received, 76% have taught or are teaching engineering in a higher education setting, 11% have industry training experience and 9% have taught in the schools. Notably, 53% of all respondents have been teaching for 10 or more years. This quick survey does not provide a comprehensive view of engineering education perspectives at our university and instead provides insights from our engineering faculty for use into our program planning.

When asked to define engineering education in their own words, our respondent's responses can be categorized as specific to (a) engineering discipline – the teaching of engineering knowledge and skills or (b) engineering pedagogy – the teaching of discipline-specific pedagogical strategies. Most of the responses fall under category A with responses like, "Teaching engineering principles and practices to students who want to be engineers" or "Teaching students the skills necessary to become successful engineers including everything from technical skills to soft skills and professional development." Eight of the responses, however, reflect category B and focus on the teaching and learning of engineering with comments like, "Teaching the engineering instructor the science behind how students learn…basically teaching the teacher how to think," or "Engineering education is the study and implementation of pedagogical techniques that are effective in specific goals of engineering education."

Although most of our respondents define engineering education as the teaching of engineering, the survey revealed faculty interest in creating engineering education programs and options. On the survey, respondents answered four questions using a 5-point scale ranging from 1 (strongly disagree) to 5 (strongly agree) as illustrated in Table II. The overwhelming majority disagree with the statement that "an engineering degree prepares someone to effectively [teach] engineering" and this recognition is encouraging to us. Sixty percent of respondents agreed or strongly agreed that our university Engineering should explore new ways to prepare future faculty/graduate students to effectively teach engineering, while 70% of respondents thought our university should explore preparing secondary teachers to do the same. Although when asked if engineering education is in need of growing as a field, roughly half of the respondents were indifferent. Answering this question without suggesting more specifics may have influenced how people responded. This preliminary survey has prompted us to consider a more indepth and more widely distributed survey to more closely examine engineering education options on our campuses.

TABLE II. SUMMARY OF SURVEY RESULTS

Survey Statement	Strongly Disagree/ Disagree	Neither Agree nor Disagree	Strongly Agree/ Agree
I believe an engineering degree prepares someone to effectively teach engineering.	62.5%	25%	12.5%
I think Engineering at our university should explore new ways to prepare future faculty/graduate students to effectively teach engineering.	12.5%	15%	72.5%
I think Engineering at our university should explore preparing secondary teachers to introduce/teach engineering topics in middle and high schools.	15%	15%	70%
Engineering Ed is a field where new programs and credentials are needed.	15%	45%	40%

B. *Alignment with our university's College of Engineering's 2021-2025 Strategic Plan*

Future program planning is aligned with our university's College of Engineering's Strategic Plan [12]. Specifically, there are three goals this engineering education program will support. At this early stage in our program development, we are solely aligning with our College's plan.

Goal: "Create and refine educational programs and platforms that support a culture of inclusivity, reflect current and anticipated trends in industry and research, are flexible to the ways students learn and resilient in the face of crises."
To align with this goal, we intend to create new and innovative instructional programs and platforms (e.g., online) that focus on inclusion, flexible learning, intersectionality, and sustainability: what is at the heart of engineering education. If, for example, we can bring these programs and topics to underserved, diverse communities by way of their educators, with resources and support that they have previously been lacking, then we are contributing to our College's goals.

Goal: "Assure equitable access for students to enter and persist in world-class undergraduate and graduate engineering programs; and increase the recruitment, retention, and success of a demographically balanced undergraduate and graduate student body by the end of 2025."
By offering new engineering education programs, we will not only be increasing interest in undergraduate and graduate studies at our university campuses directly, but we will also be creating a gateway for creating access for future students as well by educating these future students teachers. These programs will be changing the culture in secondary school (middle schools and high schools) to provide more opportunities by highlighting prospects in engineering/STEM and giving them unfettered access to prepare them to enter the engineering academic field or to succeed in today's technological world.

Goal: "In furtherance of [our university's] collaborative culture, expand the College's leadership in intra-institutional partnerships that drive global impact in research and scholarship."

The last goal delves into exploring partnerships with the College of Education for an intra-institutional partnership for co-curricular programs, such as our proposed programs—engineering education master's degree, certificate program, and STEM endorsement for teaching certificates. We seek collaborative efforts that are multi-faceted and multi-disciplinary, jointly promoted, funded, and taught by faculty from the College of Engineering and the College of Education, with a focus on the big E of STEM (Engineering).

VI. DISCUSSION AND CONCLUSIONS

Recent trends in engineering education show an increasing urgency to attract students to STEM majors and careers and to retain students in STEM degree programs. Engineering education programs can increase student success and retention by preparing engineering educators to design an effective learning experiences that maximize student satisfaction, knowledge, skills, and abilities. This working group benchmarked existing engineering education programs, reviewed existing literature on current best practices, identified our engineering expertise background and skills, began collaborating with our College of Education, recognized the many opportunities made possible by the use of online offerings, discussed in detail curriculum pathways and ultimately decided that there is a need for such a program at our institution. This WIP discusses our early progress in this field and that our findings, at this time, can appear myopic. Our intention, however, is that our process and initial findings can help others in planning and questioning engineering education opportunities.

Our university is well-positioned with Colleges of Education and Engineering to offer engineering education master's degree programs to teach its own students along with serving a broader community of current and future engineering educators. In an increasingly aggressive educational market, diversification of assets is a natural progression in the drive to stay competitive. Our College of Education has existing programs in secondary math and science education, and workforce education, but currently, no programs that emphasize the E in STEM education. By working collaboratively with the College of Education, the College of Engineering could develop and sustain a program in engineering education.

This working group concludes that a broader understanding of the need for the programs and for solutions to the current and future educational environment must be adopted across multiple colleges within our university and across the broader education and engineering communities. A demand and an opportunity to provide masters' degrees in engineering education exists for the market that our university serves and beyond. Furthermore, our university has interdisciplinary faculty uniquely qualified to undertake the worthwhile and needed task of developing said program, with work outlining the process already in place. This work encourages us to contribute to the inherent importance of engineering education and to the betterment of society.

REFERENCES

[1] A. Carberry, "Engineering Education Departments and Programs (Graduate) (redirected from Engineering)," *Engineering Education Departments and Programs (Graduate)*. [Online]. Available: http://engineeringeducationlist.pbworks.com/w/page/27610307/Engineering. [Accessed: 29-Apr-2021].

[2] A. D. Lantada, "Engineering Education 5.0: Continuously Evolving Engineering Education," *International Journal of Engineering Education*, vol. 36, no. 6, pp. 1814–1832, 2020.

[3] L. Jeganathan, A. N. Khan, J. K. Raju and S. Narayanasamy, "On a Frame Work of Curriculum for Engineering Education 4.0," *2018 World Engineering Education Forum-Global Engineering Deans Council (WEEF-GEDC)*, 2018, pp. 1-6. [Online]. DOI: 10.1109/WEEF-GEDC.2018.8629704. [Accessed: 29-Apr-2021].

[4] "Framework for P-12 Engineering Learning," *American Society for Engineering Education*. [Online]. Available: https://p12framework.asee.org/. [Accessed: 29-Apr-2021].

[5] T. Walker et al. "Designing And Implementing Graduate Programs In Engineering Education," In *ASEE Annual Conference Proceedings*, Portland, Oregon, June 2005, pp. 10.422.1-10.422.11. [Online]. Available: https://peer.asee.org/designing-and-implementing-graduate-programs-in-engineering-education. [Accessed: 24-Mar-2021].

[6] R. Brent and R. M. Felder, "New faculty members may not know how to teach, but at least they know how to do research...right?," Chemical Engineering Education, vol. 50, no. 4, pp. 251–252.

[7] M. Stains et al., "Anatomy of STEM teaching in North American universities," *Science*, vol. 359, no. 6383, pp. 1468-1470. [Online]. Available: https://science.sciencemag.org/content/359/6383/1468. [Accessed: 29-April-2021].

[8] E. J. Theobald et al., "Active learning narrows achievement gaps for underrepresented students in undergraduate science, technology, engineering and math," *Proceedings of the National Academy of Sciences of the United States of America*, March 24, 2020, S. T. Fiske, Ed., vol. 117, no. 12, pp. 6476-6483. [Online]. Available: https://doi.org/10.1073/pnas.1916903117. [Accessed: 29-Apr-2021].

[9] K. Jackson and D. Novak. *3 Strategies for Overcoming Faculty Resistance to Active Learning Techniques*. [Online] Educause Review. Available: <https://er.educause.edu/blogs/2018/6/3-strategies-for-overcoming-faculty-resistance-to-active-learning-techniques> [Accessed 24 March 2021].

[10] V. Sathy and K. A. Hogan, "How to Make Your Teaching More Inclusive: Advice Guide," *chronicle.com*, July 29, 2019. [Online]. Available: https://www.chronicle.com/article/how-to-make-your-teaching-more-inclusive/. [Accessed: 29-Apr-2021].

[11] C. Hockings, "Inclusive learning and teaching in higher education: a synthesis of research," Evidence Net, pp. 1–67, Jan. 2010. [Online]. Available: https://www.advance-he.ac.uk/knowledge-hub/inclusive-learning-and-teaching-higher-education-synthesis-research. [Accessed: 29-Apr-2021].

[12] A. A. Atchley, "College of Engineering 2021-2025 Strategic Plan," unpublished.