A New Framework for Academic Reform in Engineering Education

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Abstract

The national need for engineering education reform is widely recognized. Yet, engineering faculty find the challenges to engaging in engineering education research formidable. Perceptions of what constitutes scholarly activity in the face of promotion and tenure keep many talented and passionate engineering faculty from working in this field. However, changes in culture are occurring due to increased press for engineering education reform on many fronts and an increased availability of funding for engineering education research. The Schools of Engineering at Purdue University are proposing a new framework in which such faculty can thrive; they are evaluating the creation of programs to support engineering education. This presentation will address these issues and present for discussion a vision to legitimize, institutionalize, and advance the establishment of formal academic programs in engineering education.

I. Engineering in the 21st Century

Our future engineering graduates will enter into a world marked by rapid and global change. Distance, time, and geography are developing new meaning as a result of advances in information and computer technologies and the establishment of global partnerships and alliances that provide mechanisms for collaborations that cross disciplines, institutions, states, and countries. Proactive leadership is and will continue to be needed. Future engineering graduates need to be educated to take a leadership role in shaping events to create a better future.

Environment/workplace: Today's workplace has changed dramatically from what it was even a decade ago. Some of the characteristics of the work environment for our graduates are:

- Increasing global competition, global economy
- Knowledge-based economy
- Changing demographics
- Continuing education and lifelong learning
- Rapid technology development and change
- Shrinking product life cycles
- Quality and cost dominated products/processes
- Material and process dominated designs
- Enterprise-oriented organization
- Increasing role of "integrated" engineering

- Sustainability for natural resources
- Growing concern for biodiversity
- Increasingly biologically oriented processes/products

To successfully compete and be leaders in the future workplace, our graduates must have a world-class engineering education, be equipped with the latest technical knowledge and tools, and have adequate understanding of the social, economic, and political issues that affect their work. Engineering graduates need to be significantly better prepared to deal with information retrieval, integrating knowledge, and synthesis. They must be able to take a holistic approach to problems involving complex and ambiguous systems and scenarios and employ creative and critical thinking skills. In an increasingly global marketplace, our graduates are and will be expected to work on multinational teams, have a global perspective, and be culturally and linguistically literate. They must possess communication skills to interact effectively in the community and within the professional and political arenas. Today's ethical issues will assume global proportions and our graduates must have the strong ethical foundation they will need to deal with issues involving equitable distribution of resources, byproducts of design, proprietary information, sustainable development, environmental conservation, genetic engineering, and human cloning. They need to be familiar with legal and business aspects of engineering solutions and their social impact and have a foundation in best business practices and fundamentals of entrepreneurship.

To position our graduates to compete and lead in a dynamic future, we must first ask ourselves:

- What understandings and abilities do our engineering graduates need to have to be leaders in the 21st century?
- How will we approach educating our students so that they acquire these understandings and abilities?
- How do we assess students' development of these understandings and abilities?
- What can we learn from other institutions to help us prepare our students better?
- How will we inform and reform the K-12 pipeline about the understandings and abilities that are needed to be successful in engineering?
- How might we provide guidance to industry for more effective lifelong learning and employee development?
- How will we educate the future cadre of engineering educators to sustain and forward engineering education reform?

Perhaps the most important question we can ask ourselves is: **Are we ready to meet the engineering education challenges of the 21st century?**

The answers to these questions lie not just in the tweaking of some courses or curriculum, improving our teaching, or enhancing our efficiency, but in a willingness to consider new ways of doing business to better prepare our students for the future. Our response to the engineering educational challenges will determine the vitality, relevance, and indeed, the very future of our engineering academic programs and our engineering profession. It is our contention that engineering faculty with a passion for the scholarship of teaching and learning are uniquely qualified and well positioned to face these challenges and assume the leading position in

responding to societal needs for educating future leaders by providing preeminent engineering education programs and opportunities.

II. Why in Engineering?

The history of efforts to bring the scholarship of teaching and learning of science, engineering, and mathematics into the content departments has been plagued by the question "Why can't this work be done in a school of education?"

Consider the faculty of a typical school of education - virtually all of these individuals received a B.S. or B.A. degree, gained between three and fifteen years of experience in the classroom as a practicing teacher, and then came to the university to pursue their Ph.D. As faculty, they have developed their careers around a primary mission of working with pre-service teachers who are going to go into the K-12 classroom and/or in-service teachers who are working in K-12 classrooms. As a result, education research done by faculty in schools of education tends to focus on the problems of teaching and learning in K-12 classrooms. While research conducted in schools of education is potentially useful for those who teach in the elementary, middle and high schools in the U.S. and abroad, it does not necessarily address the problems that faculty face when teaching sophisticated topics in science, engineering, and mathematics at the university level. To address issues in engineering education reform, research methodology used by colleagues in schools of education will certainly need to be employed, but a basic understanding of engineering science and design that is far beyond that commonly found among either faculty or graduate students in education will also be required.

Engineering education as a field of scholarly activity needs to be pursued by engineers. Because they are the heavy users of mathematics, science, and technology in problem solving and design contexts, engineers possess knowledge, understandings, and skill sets that characterize what is needed for success beyond school in the 21st century. Therefore, engineers are well positioned to take a leadership role in renewing, diversifying, and nurturing a cadre of talented leaders to guide the expansion of engineering education in K-12 and improve student learning across K-16 and beyond.

III. Challenges and Opportunities for Faculty Pursuing Engineering Education

Faculty with the talent and passion for building their careers around engineering education face considerable obstacles to success and promotion. Wankat et al. discusses that very nature education research leads to skepticism among engineering faculty[1]. These differences include:

- Education research does not precisely fit either a scientific or an applied model for conducting traditional engineering research.
- The ultimate goal of education research is “improved learning”, but there is little agreement about what that means.
- Confounding factors make cause-and-effect relationship between a treatment and an outcome difficult to prove and replicate.

Wankat et al. goes on to cites a number of other professional issues including the low relative importance of the scholarship of teaching in promotion, past lack of funding for engineering education research, and the necessity for multidisciplinary collaboration with non-engineers[1].

Engineering faculty's skepticism of engineering education as a scholarly activity has created an environment at many institutions that make the pursuit of deeply focused and productive engineering education research program anywhere from difficult to impossible. In some instances, engineering faculty with a high level of interest in engineering education carry above average teaching loads and are advised to develop and maintain traditional engineering research programs to ensure tenure. These faculty pursue engineering education projects as a sideline activity that often must be accomplished with little resources (e.g. time, funding, or graduate students). Alternatively, engineering faculty pursuing engineering education are relegated to non-tenure track positions even while they perform equivalent research activities (e.g. seeking and securing funding, conducting research, and presenting research results at professional conferences and publishing them in refereed journals).

The call for engineering education reform on a number of fronts is driving the need for the establishment of the field of engineering education as a scholarly endeavor. The call for reform is exemplified in the 1994 joint project report on *Engineering Education for a Changing World* by the Engineering Deans Council and Corporate Roundtable of the American Society for Engineering Education, the 1995 Report by the Board on Engineering Education of the National Research Council, and the recent call for change by the National Academy of Engineering (NAE) leadership[2-4]. In addition, the adoption of ABET Engineering Criteria 2000 has intensified an interest in assessment of educational outcomes and promoted a recognition of the need for changes in pedagogy to achieve the varied outcomes[1].

The National Science Foundation has supported educational scholarship in engineering since the late 1980's through the Division of Undergraduate Education and the Engineering Education Coalitions program. Today, NSF support for education reform that can be linked to engineering is in excess of $200M per year. Such support "has increased the status of educational research in faculty performance reviews, improved its quality by demanding appropriate assessment of results, attracted additional engineering professors into the arena, and increased collaborations between engineering professors and professors in disciplines like education and psychology[1]."

IV. A Vision for Engineering Education at Purdue University

Our vision for engineering education at Purdue is to educate future engineering leaders who are ready for the challenges of the 21st century, and who will take leadership for shaping events and creating the future. We recognize that our future is in the hands of our students - we have the opportunity to mold and shape our destiny by preparing them well. Discovery and scholarship of engineering education as a new and exciting intellectual direction will significantly impact the nation's science and technology agenda by preparing the future cadre of engineering leaders.

Our goals are to:

- Pursue an integrated engineering education concept based on partnerships and networks across various communities/entities that can contribute to the education of future engineering leaders
- Provide world-class engineering education opportunities
- Be known for leadership in providing the engineering education research/discovery base that will support systemic reform of engineering education

- Be a leader in internationalizing engineering education by pursuing global partnerships and opportunities and broadening our student and faculty base
- Provide an environment that attracts, mentors, and retains outstanding, diverse faculty, staff, and students to pursue engineering education endeavors
- Provide the highest quality facilities for learning and discovery activities in engineering education that reflect leadership and forward thinking
- Provide guidance to industry for effective lifelong learning and employee development

V. Vision for A School of Engineering Education

To meet the goals as stated above, the Schools of Engineering at Purdue seek to create a School of Engineering Education (SEED). The mission of the proposed SEED will advance the successful components of the existing Department of Freshman Engineering and recognize the opportunities in taking a leadership role in engineering education reform. The new mission embraces the elements below:

- The first-year engineering program will be elevated to preeminence.
- Administration of the non-accredited undergraduate Interdisciplinary Engineering program will come under the School of Engineering Education. In addition, a new accredited undergraduate interdisciplinary engineering program will be created.
- A new undergraduate Engineering Education program through Interdisciplinary Engineering will be created.
- A coherent research agenda focused on student learning and learning environments will be established.
- New graduate degree programs (MS and PhD) will be offered to support the research agenda and prepare the next generation of professionals to impact engineering education reform.
- Mechanisms to enhance the potential for collaboration with faculty in the Schools of Engineering and across Purdue will be established.
- A structured outreach program will be developed and staffed to engage K-12 audiences in engineering, enhance recruitment efforts for the Schools of Engineering, provide support for educational research centers, and support lifelong learning for industry professionals.

VI. Benchmarking with Other Institutions

The new School of Engineering Education will be the first of its kind. While other institutions are beginning to move toward developing Engineering Education programs, it appears at this time that no single institution or engineering education center encompasses all of the components that are being considered here. Centers shown in Table 1 do contain some aspects of what SEED will strive to accomplish but lack academic programs in engineering education. In addition, Virginia Polytechnic Institute & State University recently received an NSF Bridges in Engineering Education planning grant (NSF Award No. 0342000) to, in part, "develop a new degree program in education to enable engineering graduates to earn a master's degree while also qualifying for licensure as technology teachers in the Commonwealth of Virginia[5]".

Although there is not one complete program after which SEED can be modeled, there are a number of centers from which we can learn and incorporate ideas into a program that fits the goals of our mission.

VII. Vision for Academic Programs

An expanded role for the School of Engineering Education will necessitate adjustment to existing academic programs and creation of new degree offerings (Figure 1). The existing Department of Freshman Engineering and the Division of Interdisciplinary Engineering Studies will be merged to form the School of Engineering Education. In addition, engineering education undergraduate, masters, and doctoral programs will be developed. A brief description of these programs follows.

First-Year Program. The Department of Freshman Engineering is celebrating 50 years of providing first-year engineering students with a firm foundation and initial understanding of engineering and career options to assist them in identifying the appropriate professional school in which to earn their undergraduate studies. Today, 1550-1700 new engineering majors enter through the Purdue University Freshman Engineering Program (FrE). Thus, FrE serves as the gateway to the Schools of Engineering with all students completing the FrE core curriculum being admissible as sophomores to the professional engineering degree programs at Purdue. In this role, FrE works closely with the Engineering Professional Schools, the School of Science, and the School of Liberal Arts, as well as industry, alumni and parents to recruit, retain, and reinforce outstanding engineering students. The FrE Program remains unique in the nation and has enjoyed great success due not only its structure but its melding of teaching and educational research. The FrE program will continue to be a key element in the SEED. However, through the expanded mission of SEED, we envision implementing more research-informed changes to the first-year engineering program. Since the first year program will continue to be controlled by the Freshman Engineering Curriculum Committee, the Schools of Engineering will be involved in all of the proposed changes. Katehi, et al. describes some potential directions for change, with a particular focus on curriculum and advising, based on current first-year experience research findings[6].

Undergraduate Engineering Programs. The Division of Interdisciplinary Engineering Studies (IDE) is a degree granting program founded at Purdue in 1969. IDE has a very flexible program leading to a non -accredited engineering degree. Students can develop their own plan of study or follow one of the more-or-less standard plans of study (e.g., acoustical engineering or inventive design engineering). IDE will be brought under the SEED umbrella and will serve as a model for two new undergraduate programs.

Table 1. A Preliminary Assessment of Engineering Education Programs in the U.S.[a]

Purdue Peer Inst.	Institution/Center	Faculty Teaching Development	Research/ Scholarship	Comprehensive Curriculum/ Graduate Program	Faculty Tenure Track Position	Faculty Positions	Staff Positions
	Arizona State University- Center for Research on Education in Science, Mathematics, Engineering, and Technology		X		0	Partial - 3 Primary - 0	4
	Colorado School of Mines- Center for Engineering Education	X	X		0	Partial - 1 Primary - 1	1
X	**Georgia Inst. of Technology-** Center for the Enhancement of Teaching and Learning	X	X		0	Partial - 1 Primary - 3	3
	Kettering University- Center for Excellence in Teaching and Learning	X			0	Partial - 1 Primary - 0	2
X	**Penn State University-** Leonhard Center for the Enhancement of Engineering Education	X			0	Partial - 2 1 tenured faculty 1 non tenure track faculty	1.5
X	**University of Illinois-** Academy for Excellence in Engineering Education	X			0	Partial - 1 Primary - 0	2
	University of Washington- Center for Engineering Learning and Teaching	X	X		0	Partial - 2 Primary - 2	2
X	**University of Wisconsin-** Engineering Learning Center	X			0	Partial - 2 Primary - 0	1
X	**Other Peer Institutions**[b]						

[a] Data is based on preliminary contact with each institution and may not reflect current state at each institution.

[b] **Other Purdue Peer Institutions:** University of Texas-Austin, California Institute of Technology, Carnegie Mellon University, Cornell University, Massachusetts Institute of Technology, Stanford University, University of California-Berkeley, University of Michigan

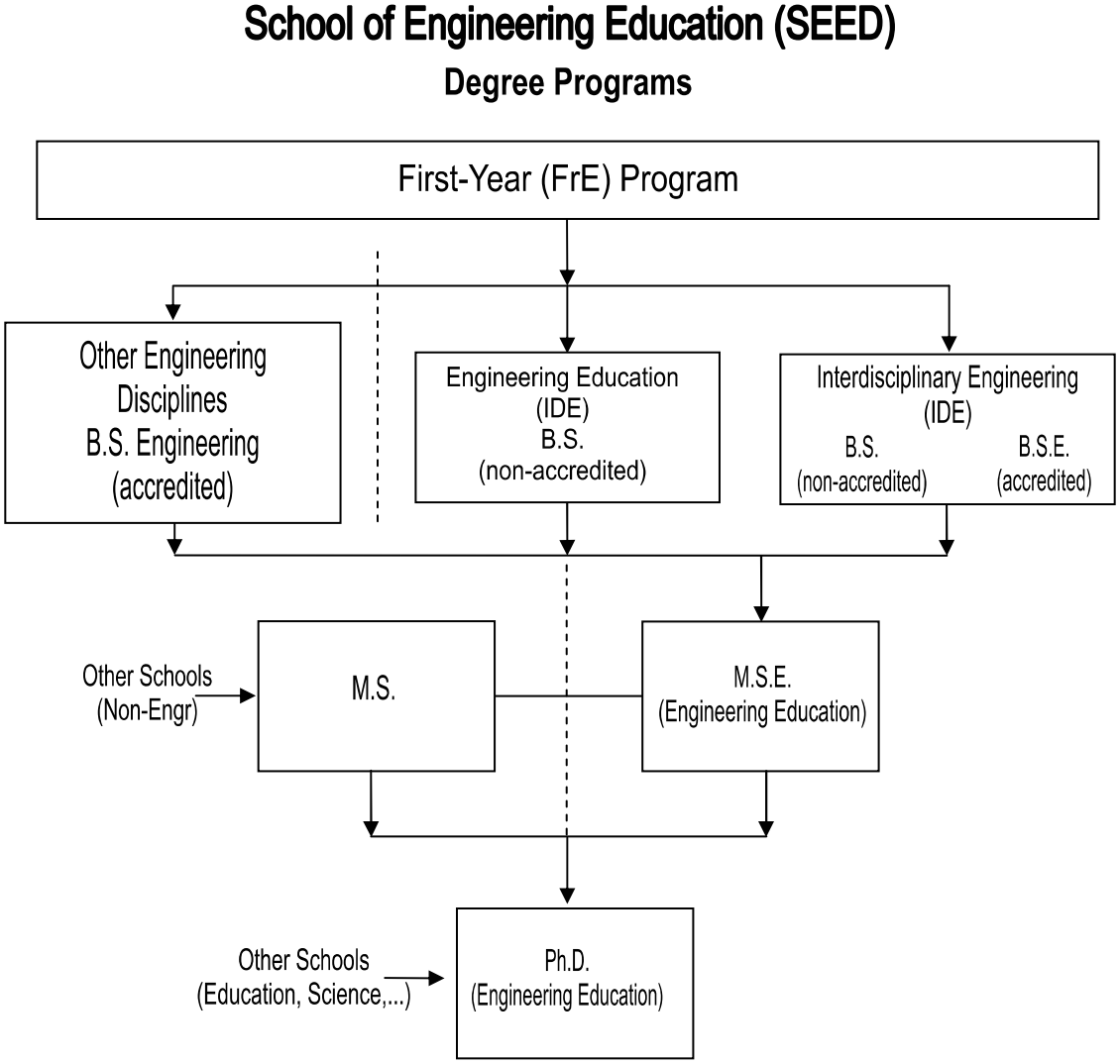

Figure 1. The proposed School of Engineering Education degree programs.

Interdisciplinary Engineering B.S. Degree. The non-ABET accredited IDE degree will continue to be offered to students who want an engineering education but have no desire to become practicing engineers (e.g., premedicine engineering, prelaw engineering, and inventive design). Retention of the current non-accredited IDE program allows students to gain the advantages of an engineering education without the ABET accreditation requirement (criterion 4) that the program educate students to become practicing engineers. The proposed degree for the non-ABET accredited program is the BS degree.

Interdisciplinary Engineering B.S.E Degree. An ABET accredited IDE degree will be created that is similar to the General Engineering programs at some other institutions and is a program for students who desire to become practicing engineers. This program might be similar to the existing accredited program at the University of Illinois at Urbana-Champaign[7]. There would be both pre-approved accredited programs such as acoustical engineering and unique programs

developed by students, but subject to the requirements of accreditation. The major differences between this plan of study compared to the non-accredited IDE plan of study would be the increased number of engineering credits required (48 versus 30) and the need to assess that students had met ABET criteria. The proposed degree for the ABET accredited program is the BSE.

Engineering Education B.S. Degree. We propose an undergraduate degree program in engineering education that will be offered jointly with the School of Education to educate students as both engineers and teachers. The proposed degree would be part of the non-ABET accredited IDE program. Students would take 32 credits of education courses including supervised teaching and would be certified to teach in junior and senior high schools. Since certification is controlled by the Indiana state government, a proposal will have to be prepared and shepherded through the government approval process to develop this new certification track. This engineering track will be modeled on the existing mathematics, chemistry, and physics education tracks, but with engineering courses replacing the advanced mathematics or science courses.

This impetus for developing a degree offering in engineering education is that engineering is one of the few major professions that most K-12 students have no personal contact with either in school (teachers, science), through direct contact (medical profession), or TV (lawyers). Because of this lack of contact many students who have the capability of becoming engineers never develop an interest. At the same time society is becoming increasingly technical and all citizens need some understanding of engineering. Six states have mandated that there will be engineering/technology in the K-12 system. Now is the time to start putting engineers into the K-12 system as teachers.

Graduates of this program would be prepared to teach high school engineering project courses (e.g., robotics or space technology), pre-engineering mathematics, and engineering design courses similar to those now taught in first year engineering programs in college. They could work with other teachers to show practical, engineering-oriented applications of mathematics or science courses. They would also be prepared for positions as technology coordinators in school systems. Some of the graduates might also be attracted to training positions with companies or working with companies that produce products for the K-12 school system. Some of the graduates would decide to continue in Engineering Education in graduate school to prepare for positions in community colleges and four year colleges and universities.

Students successfully completing the freshman engineering program in SEED may elect to remain in SEED to complete one of the IDE programs instead of transferring to one of the current Schools of Engineering. By and large, the engineering courses taken by students in the IDE programs would be selected from the large number of courses offered by the existing Schools of Engineering. In the case of the ABET accredited IDE degree, SEED will be responsible for seminar courses, a multidisciplinary capstone design course, and perhaps one or two additional courses. Assessment to ensure that students meet all ABET criteria will be focused in the SEED seminar and capstone design courses. Consideration will also be given to a requirement that students take the Fundamentals of Engineering exam.

Graduate Degree Programs. Master's and PhD degree programs in engineering education will be designed to meet the needs of students with a broad range of backgrounds and interests. The engineering education faculty will work with students to develop a plan of study that best meets their individual academic needs and career goals. In general, the master's programs will be designed for students who are interested in pursuing careers in community college or K-12 education (including teachers or math/science coordinators for school districts) or in obtaining doctorate degrees in engineering education. The PhD degree program will be designed to prepare the recipient for a career in engineering education at the undergraduate or post-graduate level. Katehi, et al. details the graduate programs and potential career paths for students with advanced degrees in engineering education[8].

VIII. Vision for Research and Discovery in Engineering Education

Within the field of engineering education, the scholarship of discovery, the scholarship of integration, and the scholarship of teaching are all relevant and seamlessly bound. To focus only on teaching is to trivialize the work and contributions of leaders in this field and the potential for the field to catalyze significant engineering education reform. While the term scholarship of teaching has come to mean more than the knowledge gained from preparing for and participating in one's classes and the earning of a reputation for excellence in the classroom, it does not reflect the breadth of scholarly activity that occurs under the engineering education umbrella. Faculty members in the new School of Engineering Education will become increasingly involved in scholarly activities that include but are not limited to:

- Quantitative and qualitative research on student learning and learning environments focusing on the abilities and skills engineering students need to develop to be successful at each stage of their academic careers and beyond.
- Development, implementation, and assessment of new instructional models, materials, and learning environments.
- Dissemination of research results to a wide variety of audiences including engineering colleagues; math, science, and technology educators; and policy makers.
- Preparation of the next generation of faculty and professionals wishing to pursue work in the field of engineering education.
- Seeking and securing funding to support research activities.

A number of current and past FrE faculty are already engaged in engineering research and have presented and published in this area. In addition, many FrE faculty have funded projects in engineering education. Most of the funded projects are conducted by multidisciplinary teams of faculty from the Schools of Engineering, the School of Education, and the School of Science. To enable SEED faculty to be competitive in securing future funding from NSF and other sources, we will establish a comprehensive and coordinated research agenda aimed at addressing engineering education reform. It is envisioned that faculty will continue or initiate research in one or more of the broad areas listed below:

- Science of learning engineering is aimed at understanding what students need to know and how it is affected at all levels within the engineering context. This research will address questions such as: "What is fundamental knowledge in engineering (now and in the future)?", "What is the nature of problem solving", "What does it mean to understand [engineering

concepts]?", and "How do we quantify understanding?"... One potential focus is the differences between learning in engineering and learning in other disciplines. Another potential focus could look at how problem-solving abilities develop and are affected. Still other areas include psychological, social and pedagogical aspects of learning, machine learning, learning technologies, and mathematical analyses and modeling of all of these. This body of knowledge can extend our understanding of learning and can enable us to connect learning research to the scientific, technological, educational, and workforce challenges.

- Pedagogy research is expected to include research on teaming, motivation, self-beliefs, learning environments, collaborative learning, diversity issues, teaching design across the engineering curriculum, and development of interventions, such as supplemental instruction and service learning.
- Technology and communication will focus on how to teach effectively through technology, how technology affects students learning, how technology can be changed to improve student learning.
- Assessment of student learning will include the development of both qualitative and quantitative assessment tools and techniques for engineering. Assessments of students' math and science preparation for engineering will enable the SEED to evaluate K-12 standards. Another aspect of this is ABET criteria-related assessment. This assessment specialty will give the SEED the capability and opportunity to impact at both the local and national levels the future direction of undergraduate engineering program assessment.
- Structure research will seek to understand how department and school structure impacts self-selection into engineering, student learning, and curriculum development and reform.
- Gender and ethnicity research will focus on issues of diversity and equity in engineering and pre-engineering.
- Outreach will include special program development, recruitment, engineering student pipeline issues, impacts on underrepresented groups, and K-12 issues.

IX. A Vision for Engineering Outreach Activities

Outreach as a component of engagement has been part of Purdue since its founding as a land grant university. Outreach programs have provided assistance to our communities and are part of our responsibility as a nation to ensure equal employment and educational opportunities for all of our citizens. The requirement of a diverse workforce to solve society's complex problems has led to many outreach programs to supplement traditional K-12 programs to direct students to exciting career and life opportunities. These and other compelling reasons have prompted many successful models for outreach across Purdue's campus.

Outreach activities in engineering have only recently been implemented as part of the recruitment efforts in Freshman Engineering, Women in Engineering Program, and the Minority in Engineering Program with focus on recruiting underrepresented populations. Activities have focused on enhancing recruitment and coordinating the previously disconnected efforts of the schools and engineering student organizations.

The new School of Engineering Education will pursue the development of outreach programs directed at K-12 students of all backgrounds. The goals will be to provide exposure to and

promote interest in engineering, create opportunities for better academic preparation, and increase the number of students recruited into engineering programs. From experience in FrE, and from the various existing outreach models, it is clear that in order to engage these students, programs must also be geared toward teachers and counselors. The SEED will seek to coordinate existing engineering outreach efforts for greater long-term impact, create new direct student initiatives with the aim of deepening engineering interest resulting in greater consideration of the engineering profession, and develop workshops, curriculum development, research opportunities, and assessment tools for teachers and guidance counselors. Working closely with faculty in the Schools of Engineering Education and the professional schools, these efforts could also include collaborating on science and math textbooks, graduate research in the application of math and science in K-12 education, and development of new instructional approaches.

Outreach activities will necessitate partnership in K-12 schools which will provide numerous opportunities for research and collaborative projects. Longitudinal studies of K-12 students and the impact outreach programs have on these students and teachers is a rich area for research. Research from this work will inform the development of curricula and outreach materials and provide assistance in training K-12 teachers.

The outreach program will also function as a resource to be leveraged for large research initiatives. Many federally funded initiatives require an education and outreach component. The outreach program proposed would provide an infrastructure to integrate such research proposals. Outreach programs can be designed and implemented using templates and resources from SEED, allowing the PI's on the research programs to focus on the technical content. The expertise of the outreach personnel and the faculty from SEED would produce stronger proposals and more effective outreach programs that leverage available talent.

X. Concluding Remarks

It is envisioned that faculty in the new School of Engineering Education will have all the rights and privileges of any other engineering faculty, including offering and teaching undergraduate and graduate courses; supervising research and graduate students; serving on a variety of school and university committees; and voting on matters related to curriculum, faculty, and school issues. Faculty will be in charge of their own destiny and barriers for their growth and professional development will be removed. At the same time, faculty will be held accountable with regard to their performance and accomplishments. Similarly, the reward and recognition structure for faculty will be very similar to other engineering faculty. Their performance will be measured in the context of their contributions to the three mission areas of learning, discovery, and engagement by their teaching performance (e.g., teaching scores, awards, and recognitions), scholarship of engineering education (e.g., research funding, publications) and service to community.

In addition, based on their record of accomplishments, and national and international recognition in engineering education, faculty in the new School of Engineering Education can advance to the highest possible ranks of faculty leadership and recognition, such as distinguished and named professorship. It is anticipated that scholarship in engineering education, science of learning

engineering, and student learning pedagogies will have similar weight as technical research for other engineering disciplines in making decisions for these prestigious ranks.

The Schools of Engineering at Purdue University are proposing a new framework to support faculty in their pursuit of careers in focused on engineering education that may serve as a model for drastically improving engineering education in the United States. It is our hope that this plan will be a step forward in legitimizing, institutionalizing, and advancing preeminent programs in engineering education by establishing the first School of Engineering Education.

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