AC 2012-4696: MINORS AS A MEANS OF DEVELOPING TECHNOLOGICAL AND ENGINEERING LITERACY FOR NON-ENGINEERS

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Abstract

It is widely acknowledged that all Americans would benefit from a greater understanding of technology and engineering crucial for daily life. Achievement of this goal has been impeded by the lengthy and highly-sequenced nature of the engineering major. The work reported here aims to develop minors or certificates to be offered by engineering departments as an approach to developing technological competence in non-engineers. Minors or certificates also a subject to be pursed to some degree of depth and provide a recognized credential deemed attractive by many students. A collaboration between Iowa State University, Ohio State University, Hope College, and Rice University is developing concepts and resources to support model engineering minors or certificates which can be adopted efficiently and widely by other school. This collaboration developed a set of Technological Literacy Outcomes for such a minor. These outcomes are similar in approach to the ABET a-k outcomes that are used for engineering degrees, but focus on developing broadly technologically literate citizens. A standard set of outcomes rather than a prescribed series of courses, allows flexibility for institutions to develop minors or certificates that are best suited to its local conditions. Results are also reported from surveys of non-engineering students regarding factors influencing potential interest in engineering literacy minors or certificates. Data obtained from potential employers regarding their perception of the value of engineering-literacy minors generally favors such minors as a desirable set of abilities valued by potential employers.

Background

The quality of life in American is dependent upon modern technology. It is also widely recognized that economic prosperity is strongly related to the vitality of a nation's technology-related industries. At the same time many issues of concern from global warming to the safety of cellphones are intertwined with our use of particular types of technological systems. Engineering programs have a responsibility to contribute to the education of all Americans regarding technology[1–5]. However, given the general level of technological illiteracy, it is evident that engineering programs have not been very effective in meeting the technological literacy needs of the non-engineering population. Educating the public about technology and engineering demands new thinking about engineering undergraduate education and a willingness to consider novel approaches to address this crisis.

Higher education has evolved significant barriers to discourage non-engineers from attempting to develop any depth of understanding about engineering and technology. The engineering major has a lengthy and high-sequenced curriculum, it is surrounded by a moat of prerequisite courses and its demands on student's time strangle efforts to pursue another field of study along with an engineering major. At the same time most science fields emphasize knowledge of the natural world and provide little practical understanding of our complex human-built technological infrastructure. Most non-engineers complete a university natural science distribution requirement in the form of a single science course. Such preparation is hardly adequate to enable non-engineers to make informed decisions about topics such as the development of fossil fuel alternatives, appropriate regulation of nanotechnology, or the importance of rare-earth elements to national security.

In the face of these challenges, minors can provide an effective means by which non-engineering majors obtain a practical and meaningful understanding of technology. Minors can provide a workable balance between a time-consuming engineering major and an inadequate one-course science requirement. Minors developed by engineering programs are not intended to provide the level of vocational skills acquired through an ABET-accredited BS engineering degree, but rather provide the general competencies needed by everyone in today's technology dependent world. Minors can provide the type of abilities advocated for non-engineers by the National Academy of Engineering in such documents as *Technically Speaking*[6] and *Tech Tally* [7]. A minor also provides a formal credential that students can use when entering the job market. Such credentials are a strong incentive and motivating factor for many students.

There is a range of interpretation regarding what defines a minor. In general minors require 4 to 6 semester-long courses in a particular area or field. This is usually 20 to 26 semester credit-hours. Minors are usually characterized by a mixture of introductory and more advanced topical or in-depth courses. Usually minors have fewer total prerequisites and a greater range of possible course sequences than majors programs in the same field.

Project Overview

The results reported here are part of an effort underway to establish a detailed understanding of the value and structure of minors offered by engineering programs for non-engineering students. This work will explore the perceived value of the minor by non-engineering students. An Important question also studied is the extent to which potential employers view the minor as a valued set of knowledge or skills. This effort builds on the promising results and related experience at Hope College, Iowa State University, Ohio State University, and Rice University[8-12].

Structure of Minors

A potential structure for the minor programs was developed and reported in detail in an earlier work[13]. These prior results are summarized here. The structure for a minor is based on development of a set of objectives and outcomes rather than a prescribed set of courses. The use of a standard set of outcomes rather than a standard series of courses allows flexibility for institutions to develop a minor or minors that are best suited to its local conditions. This is similar to the way engineering departments meet the ABET a-k requirements for engineering degrees.

The educational objectives and outcomes were developed as a structure for engineering programs developing technological literacy programs for non-engineering, undergraduate students. These objectives and outcomes are based on an analysis of five primary sources that address the issue of technological and engineering literacy.

1) *Technically Speaking, Why All Americans Need to Know More About Technology*, developed by the National Academy of Engineering[6].
2) *ABET Engineering Criteria*[14].
3) *ABET Engineering Technology Criteria*[15].
4) *Report of the Liberal Education and America's Promise (LEAP)*[16].
   This program of the American Association of Colleges and Universities is organized around a set of "essential learning outcomes", which should be developed by a contemporary liberal education.
5) *ITEEA Standards for Technological Literacy*[17].
   Although directed primarily towards secondary schools, the International Technology and Engineering Education Association has developed standards for the understanding of technology.

<u>Educational Objectives</u>
Based on a review of these related sources educational objectives and outcomes were developed. Details regarding the analysis and development is reported by Gustafson et al[13]. The minor, course, certificate, or similar program should contribute to the basic liberal education of the students such that in their personal and professional lives students upon completion will demonstrate:

1) *Knowledge* of the technological nature of the physical and natural world,
2) *Ability to* meaningfully *engage* with big questions of a technological nature, both contemporary and enduring,
3) Characteristics of personal and social *responsibility* in using and creating technology, and
4) *Capability* to *synthesize* and *advance* technological accomplishments across general and specialized domains.

<u>Outcomes</u>
The educational outcomes developed are listed in Table 1. These outcomes relate to the knowledge, ability to engage, responsibility, and capability objectives and what students acquire as they progress through the experience. At the completion of the minor, certificate or similar program students should be better able to demonstrate these outcomes.

Table 1: Educational Outcomes for Technological Literacy Programs.

Knowledge	
1	Articulate the pervasiveness of technology in everyday life.
2	Define basic engineering concepts and terms, such as systems, constraints, and trade-offs.
3	Describe the nature and limitations of the engineering design process.
4	Explain some of the ways technology shapes human history and people shape technology.
5	Compare the benefits and risks that all technologies entail, some that can be anticipated and some that cannot.
6	Identify the effects of technology on the environment.
Ability to Engage	
7	Describe the development and use of technology and evaluate trade-offs including a balance of costs and benefits both economic and social.
8	Identify technology that appropriately reflects the values and culture of society for which it is intended.
9	Give examples of relationships among technologies and connections between technology and other fields of study.
Responsibility	
10	Can identify and analyze professional, ethical, and social responsibilities as related to technology.
11	Participates appropriately in decisions about the development and use of technology.
12	Demonstrates an interest and ability in life-long learning and self-education about technological issues.
Capabilities	
13	Formulate pertinent questions, of self and others, regarding the benefits and risks of technologies.
14	Obtain and interpret information about new technologies.
15	Discriminate the role of problem solving for troubleshooting, invention, innovation, research and development.
16	Function effectively on teams with varying technological expertise.
17	Communicate effectively, both orally and in writing, regarding technological issues.
18	Think critically and creatively regarding technological issues including an ability to assess, rank, or to compare proposed designs on the basis of the desired outcomes, consequences, and constraints.

Employer and Manager Surveys

For a minor offered by an engineering program to gain popularity among non-engineering students an important element will be the extent to which potential employers view the minor as a valued set of knowledge or skills. An effort was made to establish the perceived value of the minor by employers. Efforts focused on obtaining information from current and potential employers of students completing the minors.

A survey was developed base primarily on the objectives and outcomes listed in Table 1. The survey was directed to human resources directors and engineers working in management positions. A total of 25 anonymous responses were received. Table 2 shows the type of work carried out by the organization at which the survey respondent was employed. The largest number of respondents were engaged in manufacturing. Also included were individuals in the transportation, health care, and construction industries. The significant representation of employers and managers engaged in manufacturing industries provides some assurance that these respondents have opinions about engineering-related skills that are well-informed by their workplace experiences.

Table 2: Industries Represented by Employer/Manager Survey Respondents

Industry	Percentage of Respondents
Construction	4
Health Care	4
Manufacturing	76
Transportation	4
Other	12

The survey respondents are well-acquainted with non-engineers working in technically-related industries. One hundred percent of the survey respondents work with non-engineers. Almost seventy five percent of the respondents hire non-engineers. Details regarding the interaction of the respondents with non-engineers are given in Table 3.

Table 3: Percentage of Employer/Manager Respondents Hiring and Working With Non-Engineers.

Interaction with non-engineers	*Never or Almost Never*	*Sometimes*	*Often*	*Always or Almost Always*
How often do you WORK WITH non-engineers?	0	12	52	36
How often do you HIRE non-engineers?	29	38	25	8

The survey listed the proposed outcomes characterizing technological literacy. The respondents were asked to rank each item on a 5 point scale from "Not at all Important," to "Very Important." A ranking of "Not at all Important," was assigned a numerical value of 0. The ranking of "Very

Important," was given a numerical value of 4. An overall score for each outcome was determined by averaging the results from all respondents.

A summary of the results for the employer survey is given in Tables 4 and 5. A total of 21 different outcomes were evaluated. Table 4 shows those outcomes that were ranked highest by the employers and managers. A total of 11 outcomes had an average score of 3.0 or higher on the 4-point scale used. Table 5 includes the results for the remaining 10 outcomes.

The outcome for non-engineers ranked highest by employers and engineering managers was the ability to function effectively on teams with varying technological expertise. Also most highly valued were the abilities to communicate effectively on technological issues and an understanding of basic engineering concepts. The outcomes considered next most important included the ability to evaluate trade-offs, critical thinking, an ability to work independently, and skills in discriminating the role of problem-solving in troubleshooting, invention, innovation and research.

A set of nine of the outcomes emerged in the middle range of importance on the employer survey. These outcomes include an ability to engage in life-long learning and self-education about technological issues, familiarity with the nature of the engineering design process, the ability to formulate pertinent questions about the benefits and risks of technologies and a facility in obtaining and interpreting information about new technologies. Also viewed as valued were knowledge of engineering areas, the ability to carryout a risk-benefit analysis, and the ability to identify the specific type of expertise needed to solve a particular technical problem. The ability to identify ethical responsibilities and skills in articulating the pervasiveness of technology in everyday life received similar rankings.

Five of the outcomes were perceived as less important by the employers and engineering managers. These outcomes included: identifying the effects of technology on the environment, and an ability to provide examples of relationships among technologies and connections between technology and other fields of study. The lowest ranked outcomes were: an ability to identify technology that appropriately reflects the values and culture of society for which it is intended, participating appropriately in decisions about the development and use of technology and explaining some of the ways that technology shapes human history and people shape technology.

Table 4: Employer Survey Results for Outcomes Rated as 3.0 or Higher on Scale of 0 - 4.

Rank	Topic	Outcome Question As Worded on Survey	Score (Max=4)
1	Team Effectiveness	Function effectively on teams with varying technological expertise.	3.56
2	Communication	Communicate effectively, both orally and in writing, regarding technological issues.	3.52
3	Engineering Concept Knowledge	Define basic engineering concepts and terms, such as systems, constraints, and trade-offs.	3.44
4	Role of Problem-Solving	Discriminate the role of problem-solving for troubleshooting, invention, innovation, research and development.	3.32
5	Critical Thinking	Think critically and creatively regarding technological issues including an ability to assess, rank, or to compare proposed designs on the basis of the desired outcomes, consequences, and constraints.	3.28
6	Evaluate Trade-offs	Describe the development and use of technology and evaluate trade-offs including a balance of costs and benefits--both economic and social.	3.20
7	Work Independently	Work independently and find creative solutions to problems.	3.16
8	Life-long Learning	Demonstrate an interest and ability in life-long learning and self-education about technological issues.	3.04
9	Limitations of Engineering Design	Describe the nature and limitations of the engineering design process.	3.00
10	Formulate Questions	Formulate pertinent questions, of self and others, regarding the benefits and risks of technologies.	3.00
11	Obtain Information	Obtain and interpret information about new technologies.	3.00

Table 5: Employer Survey Results for Outcomes Rated Lower than 3.0 on Scale of 0 - 4.

Rank	Topic	Outcome Question As Worded on Survey	Score (Max = 4)
12	Identify Expertise	Know the specific type of expert with whom to consult to solve a particular technical problem or issue.	2.96
13	Risk-Benefit Analysis	Compare the benefits and risks that all technologies entail, some that can be anticipated and some that cannot.	2.92
14	Articulate Pervasiveness	Articulate the pervasiveness of technology in everyday life.	2.88
15	Ethical Responsibility	Identify and analyze professional, ethical, and social responsibilities as related to technology.	2.80
16	Engineering Areas	Describe the type of knowledge specific to various engineering disciplines and the areas of expertise represented by each engineering fields.	2.76
17	Effects on Environment	Identify the effects of technology on the environment.	2.68
18	Technological Connections	Give examples of relationships among technologies and connections between technology and other fields of study.	2.44
19	Technology and Values	Identify technology that appropriately reflects the values and culture of society for which it is intended.	2.40
20	Technology Development	Participate appropriately in decisions about the development and use of technology.	2.24
21	Social / Historical Interactions	Explain some of the ways that technology shapes human history and people shape technology.	2.00

Overall the employers and managers surveyed considered the set of outcomes describing the minor as appropriate and valuable for non-engineers working in technical organizations. Table 6 contains a summary of the responses.

Table 6: Overall View of Value of a Minor by Employers and Managers.

Question	Agree or Strongly Agree (%)
I would view a minor as defined by the skills and abilities described in the previous questions as a valuable educational credential for a non-engineer.	84
Individuals who possess the skills and abilities described in the previous questions would be valuable to my organization.	80

Respondent to the employer and manager survey were given the opportunity to provide free-response, open-ended input. A selection of these open-ended responses are included in Table 7. Most of the responses view a minor favorably, although one respondent cautions against the problems that could result from training as "one-half" an engineer. Other valuable abilities listed include familiarity with engineering economics and conflict resolution and mediation skills.

Table 7: Selected Free-Response Input from Employers and Managers.

Fields are changing so rapidly, rather than specific fields, a very broad overview would be preferred, focus on…basics. *In my opinion, a minor in engineering would be similar to being a 1/2 engineer. It can be very dangerous to an organization if someone has a little engineering background and the organization is using their limited knowledge to make decisions.* *It appears that the survey hit all the key elements that come to mind. Keys are an understanding the economics of engineering decisions and being able to communicate within multi-disciplinary teams/skill levels.* *Non-engineers with the ability to understand a discussion of a technical nature and have a sense of the relative advantages, disadvantages, benefits, and risks would be extremely useful to any organization that does any amount of engineering work.* *Problem solving skills conflict resolution/mediation skills.*

Student Focus Groups

To determine views of non-engineering students regarding technological literacy minors focus groups were conducted. A series of focus groups were conducted with non-engineering students at Rice University and Ohio State University. The focus groups were conducted by an experienced focus-group facilitator. A total 10 different groups were conducted with a combined total of 64 students.

The focus groups intended to determine the issues and concerns of the non-engineers. To promote discussion, the groups were asked questions including the following: What would motivate students to select a minor? How should a minor be presented, promoted, or advertised to indicate its potential appeal or value to non-engineering majors?" Would someone in your major be attracted to a minor? What types of majors would be attracted to this? What are some of the potential benefits to a student who chooses a minor? Can you see any drawbacks to a minor from engineering? Would the minor be more attractive if one of the electives could be satisfied by a practical experience such as a summer internship with an engineering company, working on an Engineers Without Borders project, or working on a senior design team with engineering students?

It was found that the information from the focus-group participants centered around two themes. First, students embraced the idea of a minor because of its focus on project-based learning, critical thinking, problem solving, and employability. This theme emerged regularly among all of the groups of students interviewed. Students in these focus groups valued graduating from college with an attractive set of skills and experiences. They could certainly see a minor as contributing to such skills and experiences.

Second, students expressed interest in clarifying the identity of a minor. Issues such as how much technical background would be required, how much technical information would be taught in the courses, and how general (engineering principles) versus specific (engineering applied to medicine, law, environment) the coursework would be. Although a framework was described to them at the beginning of the focus group, students still noted concern over the extent to which such a minor would look like an engineering major (with fewer courses and possibly fewer pre-requisites) or whether it would be something qualitatively different.

Further clarification of the student perceptions of the identity of a minor appears to be a critical point to consider moving forward with the overall question of technological literacy of college students. Once the content and form of the minor are articulated, efforts can be made to address that content and form in specific courses.

Conclusions

Results available thus far are encouraging for the development of a minor offered by engineering units applicable for students who are not engineering majors. A set of Technological Literacy Objectives and Outcomes have been developed for such a minor. The use of a standard set of outcomes rather than a standard series of courses allow flexibility for institution to develop a minors that are best suited to its local conditions. Survey work conducted with potential employers indicates that employers and engineering managers view the abilities described by the technological literacy outcomes as desirable skills for non-engineers. The employers view an individual with such a minor as a potentially valuable employee. Surveys conducted with students who are potential constituents of such a minor program show that students value the set of skills and abilities defined by a minor from engineering but would appreciate additional clarification of the specific technological literacy goals and organization of courses in the program.

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