Constituent Influences on Engineering Curricula

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Introduction

It seems that engineering education has lost track of the big picture of what engineering curriculum is and should be. Curricula should be designed within the context of a good understanding of the components of the curriculum and the broader context surrounding the curriculum.

The topic of changes in engineering education is often used without specificity. We have decided that curriculum change usually consists of moving the boundaries that make up the elements of the engineering curriculum. Boundaries exist between the components that comprise the engineering curriculum. These boundaries change, or move in response to the various calls for curriculum change. Therefore it is important to not only define the boundary locations, but also the contents within the boundaries. For example, if you asked engineering educators what skills an engineering education should provide its graduates they would probably use words like graduates should be well-grounded in analysis skills (problem solving capabilities); able to synthesize (do engineering design); and have essential social skills including both written and oral communications, an understanding of ethics, teamwork, leadership, etc. Therefore, if these are the components of the curriculum then our view of curriculum change is about how much of each of these components should be included in an undergraduate engineering program.

The early origins of engineering education in the United States grew out of the apprenticeship roots of the profession. Up to the time of World War I, engineering education included more practical training than theory and mathematical analysis. Engineering education in the U.S. started to change after World War I as an influx of European professors brought along their more scientific and mathematical tradition involved with research.

Following World War II, undergraduate engineering programs became more and more analytical. Because of the success of physicists during World War II with design and development of weapons like the atomic bomb and radar defense systems, engineering came to be more and more like applied physics. The Russian launch of Sputnik in December 1957 accelerated the movement of the engineering curriculum toward applied physics. Until the mid 1970s, few engineering programs contained any design projects and social courses in writing (composition) were confined to successfully passing, or having waived based on some
examination, the university freshman writing course. Some engineering schools required a speech course and/or an ethics course but this was as far as it went. Looking over the curriculum at the highest level, the breakdown might have been 90-95% analysis, 0-5% synthesis, and 5% social. Clearly, such a curriculum did not meet even the goals of engineering faculty let alone the business and industrial needs. Beginning in the early 1980s much discussion ensued about reforming engineering education and with it, the engineering curriculum. These curricular reform discussions were initiated by engineering educators, industrial leaders, and the professional societies.

A new emphasis was placed on the acquisition of synthesis knowledge, that is, the ability of engineering graduates to conduct design and development of open ended problems. This was reflected in the growth of the many national design competitions that currently exist, e.g. concrete canoes, human powered vehicles, walking machines, chemical powered vehicles, etc. This became a time of shifting the boundary in the curriculum to include more synthesis-based knowledge.

With this new emphasis on synthesis came a concomitant call for greater social skills. A key component to good design is an ability to communicate the rationale for design decisions, in addition to the technical aspects of the design. So a current push in engineering education is to move the social skills boundary to include a greater proportion of social skills in the engineering curriculum.

Globalization of engineering careers also places new demands on social knowledge. Because engineering graduates now compete for jobs around the world and with graduates from institutions in many other countries, all of our graduates must have basic knowledge of foreign cultures and languages.

The launch of the Sputnik satellite by the Russians in December 1957 was a ‘defining moment’ for U.S. engineering schools and its curricula. This event was externally supplied and resulted in the change of engineering curricula to be based almost entirely on analysis courses. In subsequent years, the various stakeholders of the curricula have chipped away at individual components without consideration of overall integration or a consistent set of goals for engineering curricula to meet.

In this paper we present a high level view of engineering curricula. The view consists of the knowledge taxonomy of analysis/synthesis/social skills described above and the relative proportion of each knowledge type in the overall curriculum. Decisions about the boundary locations are then discussed in the context of the many constituents that claim various levels of ownership of the curriculum, including: industry, professional societies, state governments, university administration, faculty, parents and students, funding agencies such as NSF and DOE, and other foundations. Each of these groups has an influence on the shaping of the engineering
curricula. The ubiquitous use of technology both in the teaching and practice of engineering also plays an important role in curriculum but usually not at the highest level. Rather, technology discussions should enter when individual courses are planned and the technology can be matched to the course outcomes.

Description of Issue

There are many ways for defining the components of the curriculum. The most common approach is to focus on the discipline aspects. For example, the American Society of Civil Engineers still requires that programs must provide proficiency in five major areas (sub disciplines) of civil engineering. As an alternative we propose a system that uses three categories: analysis, synthesis, and social. This system has the advantage of crossing disciplinary boundaries and is flexible enough to handle most, if not all curriculum components.

Analytical knowledge is common to all engineering curricula. When people refer to engineering as an applied science, this usually refers to the level of analysis in the curriculum. The various disciplines are mostly distinguished by the particular analytical knowledge included in the curriculum although most have a similar core of mathematics, physics and chemistry foundation courses. However, still lacking in most programs is a foundation course in the biological sciences as engineering turns more and more towards living systems.

Synthesis refers to the ability to combine various analytical capabilities within the context of design. This portion of the curriculum is mostly covered in some type of senior capstone design experience. The differences between the disciplines are not as significant as is the case with the analytical portion of the curriculum. Although each discipline has design aspects particular to the discipline, there is greater commonality in this portion of the curriculum in terms of approaches and objectives.

We use the term social to refer to the many people oriented skills necessary to succeed as an engineer. For example we would include foreign languages, cultural awareness, writing and public speaking abilities in this category. It is this category where the various engineering curricula are the most similar.

Boundaries

Curricula changes in engineering involve moving the boundaries between the three components of the curriculum: analysis, synthesis, and social. When we refer to moving these boundaries we are talking about the relative percentages of each component in the curriculum. Unfortunately, these boundaries are shifted without explicitly acknowledging either their starting location, or what is the desirable final location. It is very easy to start shifting the boundary from one side without understanding the implications of the material on the other side of the boundary. This
issue is complicated by the many groups (shareholders) who attempt to influence the engineering curricula. Some of these groups are external to the university; while others are subgroups residing within academe. Each group tends to have its own agenda and does not always appreciate the role of the other demands on the curriculum. An important point to all discussions concerning changes to the curriculum must be the question of what knowledge shall be sacrificed when boundaries are shifted.

Constituents

Constituent groups can be distinguished from each other by whether they have direct or indirect influence. The group that may have the most direct influence on engineering curricula is the accrediting agency: ABET (Accreditation Board for Engineering and Technology). For many years, ABET specified the content of engineering curricula via minimum requirements for credit hours in various topics—mostly analytical topics. Professional societies also exert some direct influence through their cooperation with the ABET process. Other groups that can have direct influence include state governments in the case of state universities, university administrations and governing board. Indirect influence tends to come from groups that fund new curricular approaches, e.g. the National Science Foundation, Department of Education, and various private foundations. A group that is becoming more active in curriculum issues is the employers of engineers. This group is providing advisory input to many colleges and departments, often as a response to ABET requirements.

Accreditation

The single most influential group driving curriculum reform in engineering is the Accreditation Board for Engineering and Technology, ABET. As the only accreditation agency, ABET directly sets the standard for engineering curricula. Prior to the year 2000, ABET’s approach was prescriptive in nature where specific components of the curriculum were required in terms of minimum credit hours. These requirements were mostly analytical components of the curriculum but general education minimums were also stated. Starting in the year 2000, ABET undertook a major shift in policy by focusing on program outcomes rather than program inputs. Instead of listing curriculum components, outcomes, currently eleven, are now required:

“(a) an ability to apply knowledge of mathematics, science, and engineering
(b) an ability to design and conduct experiments, as well as to analyze and interpret data
(c) an ability to design a system, component, or process to meet desired needs
(d) an ability to function on multi-disciplinary teams
(e) an ability to identify, formulate, and solve engineering problems
(f) an understanding of professional and ethical responsibility
(g) an ability to communicate effectively

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(h) the broad education necessary to understand the impact of engineering solutions in a 
global and societal context  
(i) a recognition of the need for, and an ability to engage in life-long learning  
(j) a knowledge of contemporary issues  
(k) an ability to use the techniques, skills, and modern engineering tools necessary for 
engineering practice.”

In this list, each can be classified as being analytical: a, e, k; synthesis: b, c, k; and social: d, f, g, 
h, i, and j. Based on this classification, there is a significant shift to social abilities/outcomes.

**Industry**

Many engineering departments employ industrial advisory boards to assist with the ABET 
mandated outcomes assessment program. Industry tends to want it all: graduates who are highly 
trained in the analytical skills, can synthesize–design, and who have the social skills necessary to 
be immediate productive members of the company. Whereas in the past industry often accepted 
the responsibility of developing the social and synthesis aspects of engineering graduates, the 
pressure for productivity from recent graduates requires students to be competent in all aspects of 
the profession upon graduation.

**Professional Societies**

Professional engineering societies provide guidance and requirements that are part of the ABET 
accreditation process. Review of the program criteria included in the ABET criteria indicates that 
the professional societies concentrate on the technical components of the curriculum, typically 
listing areas of technical competencies within the various disciplines. Using our knowledge 
taxonomy from above, professional societies’ top priority is the analytical aspects of curriculum, 
followed by synthesis, with little mention of the social aspects of engineering.

A current effort by the American Society of Civil Engineering has developed a new Body of 
Knowledge envisioned for civil engineering graduates in the future. This effort has resulted in 
five additional outcomes that extend the ABET criteria described above. The natures of these 
ew criteria tend to fall on the social/analytical border. Several of these refer to skills in 
management and business topics, leadership skills, and public policy along with the requirement 
for a specialized technical area. As one can see from this list, the push is for both more technical 
material and social skills such as leadership and policy related topics.

**State Government**

State institutions of higher education are held accountable by state governments. Recent national 
trends seem to indicate that the goal of most state governments is to encourage degree programs
to fit nicely into standard, one size fits all packages. For example, many states are pushing for limiting total credit hours for BS and BA degree programs – with little or no thought given to the content breakdown of those credits. Also, many of these people falsely believe that students do not graduate in four years because they must take too many credits. In fact, the reason students take longer than four years to graduate is often based on a combination of factors that may include: poor high school preparation, a need to work to pay their way through college, a desire to earn a minor, and commitments to external activities other than academic studies.

University Governing Boards and Administration

University administration tends to view curriculum through two main lenses: general education and overall credit requirements. General education requirements form a major component to any well designed higher education curriculum. This is especially important for engineering as the general education requirements complement the heavy emphasis on science and analysis in a typical engineering curriculum. In fact it is required for accreditation: “a general education component that complements the technical content of the curriculum and is consistent with the program and institutional objectives,”2 (ABET 2003, Criterion 4 Professional Development, part (c)).

Two difficulties can arise from general education demands. First, it is challenging to integrate general education requirements so that they complement the other components of the curriculum. If we become very specific in which general education courses should be taken, students lose the main opportunity they have for having flexibility in their curriculum. On the other hand, it is very easy to view these requirements as distractions that a student must satisfy and allow them complete freedom to choose from a laundry list of courses. This can result in general education courses making little connection to the engineering curricula. Second, if these programs become too large in number of required credits, it can displace important technical topics. As schools impose more restrictions on the students by requiring larger general education programs, because there are few if any free electives in the engineering curricula, technical course content may be sacrificed for the new requirements.

The total number of credits also seems to be a major concern for university administration and governing boards. There is a growing perception that all undergraduate programs should require the same number of credits, with 120 being the current favorite. This artificial limit can force engineering programs to reduce credits to fit into a curriculum credit box designed for non-engineering programs.

Faculty

One group that pushes with great energy for analytical content in the curriculum is the engineering faculty. A majority of current engineering faculty are a product of the highly
analytical curriculum described above. This results in faculty who are most comfortable teaching analysis -topics they know best. As a group, faculty are also likely to push for greater discipline rich curriculum (analytical topics) and less likely to push the social and synthesis topics. This is probably especially true for departments with large faculty groups. Each specialty group wants to contribute to the undergraduate program with their own discipline course--this can quickly add up to many technical courses beyond the basic engineering science core courses.

**Parents/Students**

Parents and students may have the most pragmatic view of curriculum. One of the most important questions for these groups is: Will this degree lead to a high paying job upon graduation? This often colors the choice of topics students desire to take. The idea of becoming a well educated individual takes a secondary role to becoming an employable graduate. This trend would then tend to cast the boundary further towards the social and synthesis sides of engineering where preparation for design becomes a critical skill. Most students do not develop a great appreciation of the importance of detailed analytical courses that are not immediately tied to future employment.

**Funding agencies**

**National Science Foundation**

The National Science Foundation (NSF) has played a key role in engineering education reform. Through a series of conferences and workshops from the mid to late 1980s, a need for significant changes in engineering education was identified. Among the changes identified were: a shift from disciplinary approaches toward broader synthesis of knowledge and interdisciplinary modes of operation, including the ability to work in teams; a systems approach to problem-solving; greater knowledge and consideration of social, environmental, and other implications of problem-solving efforts, along with management skills and a capacity for life-long learning; increased ability to attract and retain students in fields of engineering, as well as increased participation of under-represented groups; more emphasis on engineering practice, including early opportunities to encounter the design process; and interaction with industry. The context of these changes concerned the ability of U.S. industry to remain competitive in the emerging global economy through rapid and successful innovation.

NSF responded to this challenge in 1989 with the announcement of the Engineering Education Coalitions, an initiative to establish a number of coalitions of engineering institutions in a multi-year effort to respond to the following vision and goals:

- To produce a dramatic increase in both the quality of engineering education and the number of degrees awarded in engineering, including those to women and underrepresented minorities;

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To design, implement, evaluate and disseminate new structures and approaches affecting all aspects of undergraduate engineering education;

To establish new linkages among all engineering institutions.

Six coalitions were funded. ECSEL, which stands for Engineering Coalition of Schools for Excellence in Education and Leadership, planned to incorporate design throughout the undergraduate engineering curriculum, as well as recruit and retain more women and underrepresented minorities in engineering. Synthesis was founded on the "synthesizing" of the teaching and learning process and its facilitation through advanced information technology. Gateway sought to develop a combination of curriculum integration, faculty and student development and "embedded educational technology." Its starting point was the "E4" integrated curriculum developed at Drexel University. SUCCEED’s strategy was the development of a model "curriculum 21" aimed at the 21st century that combined an integrated engineering core with the sciences and humanities. The Foundation Coalition was based on an integrated freshman curriculum originally developed at Rose-Hulman Institute of Technology, combined with similar efforts at Texas A&M. The Greenfield Coalition for New Manufacturing Education differed from the other coalitions. Its focus was on manufacturing engineering and engineering technology.

New courses developed by the coalitions demonstrated the variety of features desired by NSF: e.g., students working in teams rather than independently and including cooperative learning, especially in the earlier undergraduate years; increased use of modern educational technology, with computer-based methods of delivering courses increasingly taking the place of traditional lectures; and integration of engineering with other disciplines, such as mathematics, physics and chemistry, writing courses, and social sciences and humanities more generally. Many of the courses resulted in increased interactions with industry, with firms sponsoring courses and providing equipment, supplies, and guest teachers. One enhancement was ‘just-in-time’ teaching, where concurrent lecture and laboratory courses are sequenced so that lecture topics are covered just as they become needed in the laboratory, rather than have the lecture and laboratory courses proceed nearly independently. As a result of the NSF coalitions, the most pervasive innovation across the nation’s engineering schools was the introduction of meaningful engineering experiences for first year students, usually in the form of realistic design projects. Therefore, to date, NSF’s contribution is to support the addition of synthesis and social activities to the undergraduate engineering curriculum.

**Department of Education**

The Department of Education (DE) is also involved with curriculum reform through programs such as the Fund for the Improvement of Postsecondary Education. (FISPE) The DE tends to support broad improvements to higher education and does not support their own specific agenda in related to the type of curriculum content discussions presented in this paper. A guiding
principle for the FIPSE program is: “… focus on widely felt issues and problems in postsecondary education, rather than on special interest groups or prescribed solutions.”

Other Foundations

Other foundations such as the Sloan Foundation and the Pew Charitable Trust are supporting engineering curriculum reform. The Sloan Foundation has supported a number of initiatives in the use of technology and, in particular, asynchronous learning networks for offering courses over the World Wide Web. The Pew Charitable Trust has primarily supported efforts to reduce the costs of courses. Neither of these efforts directly involves the distribution of credits among analysis, synthesis or social activities.

Conclusions

Change in engineering education is driven by a combination of the desire of the many constituent groups described above and defining external moments such as the Russian launch of Sputnik. It is our conclusion that future engineering curricular reform should be based on a curriculum model that explicitly describes the curriculum using comprehensive categories for the entire curriculum. Our proposed taxonomy breaks the curriculum down into three categories: analysis, synthesis, and social. Further, we submit that curriculum change fundamentally involves the relative position of the boundaries between these three components in the curriculum.

The reform of engineering curricula is a topic of serious discussion with the many constituent groups described herein. Unfortunately, these groups are not talking with a single coherent voice. Therefore, it seems that there is need for a new ‘defining moment’ to drive future curricular reform. But this time instead of waiting for some external event, engineering faculty must take the initiative and state our own ‘defining moment,’ for example, our choice is the globalization of engineering careers. Taking such a stand will enable the engineering curricula to start over from a clean slate resulting in curricula that meets the needs of globalization. A modern engineering curriculum could easily now require 15 to 20% synthesis and perhaps as much as 20% social abilities leaving the analysis portion of the curriculum reduced to 60 to 65%. This is a dramatic change from just 25 years ago. Because of all of these changes, many engineers are calling once again for a five year curriculum. However, it is hard to believe that this movement will be embraced because it simply turns students off and declining enrollments are already a major concern. Our ideas expressed here should enable each engineering faculty to begin curriculum planning and development by addressing the overall needs of their students in order to select the appropriate divisions among analytical, synthesis and social achievements of their students.

There are obviously many stakeholders and the pressures on the curriculum that are placed on it by all the constituent interests are huge considering a limited four year curriculum. Certainly,
the stakeholders are placing much more emphasis on synthesis and social abilities than previously placed there. Much dialogue will be required in order to satisfy these constituents.

The implications from this paper also impact faculty divisions. To truly address synthesis in all programs, design faculty need to be hired or developed. Much of design is independent of the discipline so these are faculty who can range across departments. A synthesis faculty working across departmental boundaries would also lead to more truly interdisciplinary design efforts. We can envision a future college of engineering with discipline specific analytical faculties, a design faculty that works closely with analytical faculty and a separate set of faculty that are primarily responsible for developing social abilities in the students. Departmental independence of faculty involved in social development is even more pronounced. We believe that many engineering faculty take far too much credit for social aspects, for example, for teamwork development students are given an assignment and then told ‘to work in teams.’ This is rather like throwing students into the middle of the lake and telling them to swim to shore and then taking credit for those who make it.

Once the appropriate boundaries are determined by the faculty, then individual elements of the curriculum may be selected. Again, outcomes must be the prioritized and courses selected based on achievement of these outcomes. At this point, use of technology can be matched with the course objectives to determine whether or not or even how much technology should be incorporated into each course. Pedagogy should dictate technology use rather than selecting the technology and then building the course around it. These issues will be addressed further in a subsequent paper.

Bibliographic Information


Biographic Information

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