A Topical Analysis of Mechanical Engineering Curricula

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ABSTRACT

This study has dissected the current curriculum in mechanical engineering into a list of required topics. The list indicates what material is currently considered to be the essential body of knowledge for graduating mechanical engineering students. It also provides a measure of the extent to which curricula differ from institution to institution. There is similarity in core material required among the institutions which we considered, but each one adds distinct requirements which give it an individual flavor or emphasis. The list reveals some of the differences among degree programs. While institutions have adjusted curricula to conform to the ABET engineering criteria, how they fulfill the “technical skill” outcomes is clearer than how they fulfill the “professional skill” outcomes. This survey shows that dissecting a degree program into required topics is useful for curriculum reform, as it provides a baseline to study the curriculum at a level more finely grained than a course.

Keywords: curriculum, mechanical, topic

I. INTRODUCTION

Estimates of unfilled jobs in the United States requiring technology skills range from 500,000 to one million [1]. In the U.S., the number of students earning engineering baccalaureates each year is roughly 73,000 [2]. Thus, unless we increase the proportion of students who choose to study engineering, we will find it impossible to meet the increasingly technical needs of business and other organizations in the public and private sectors.

Despite these workforce shortages, the engineering curricula in academic institutions have hardly changed in decades and course titles vary little from institution to institution. Engineering curricula have traditionally been structured with critical paths that tend to be quite long. For instance, one must take calculus before physics, physics before statics, statics before dynamics, etc. The net result is that the traditional engineering program requires a commitment to the field from freshman year, or acceptance that a degree will take more than four years to earn. This discourages students with limited exposure to engineering prior to college from ever joining the technically trained workforce.

Further, the current curricular structure tends to divorce academic fundamentals from applications, which are presented only in the advanced courses during junior and senior year. Most freshmen and sophomores have not been exposed to engineering as it is practiced [3].

These factors prompt a high attrition rate from engineering, currently 38 percent of majority students and 64 percent of minority students [4, 5]. The result is a culture of exclusion, in which pride is invested in how arduous a program is, rather than a culture of inclusion that would strive to maximize the success of all students expressing an interest in engineering as a career.

In this context, our goal is to take a fresh look at the engineering course requirements with an aim of making the field more attractive without sacrificing technical rigor. We believe that this is possible through greater integration of engineering, science, and mathematics; integration of nontechnical and technical subject matter; shorter critical paths; greater focus on the impact of engineering on the human experience; and more and better team experiences [6–8].

We have chosen to focus our immediate attention on mechanical engineering. Mechanical is the largest of the engineering disciplines. It ranks first in undergraduate enrollment and first in the number of baccalaureates awarded, accounting for 19.4 percent of all engineering baccalaureates in 2004 [2]. Mechanical engineers comprise 16.3 percent of the total engineering workforce [9].

There is a team of eight academic institutions working on this project. The members are California State University at Los Angeles, Howard University, Johns Hopkins University, Michigan State University, Smith College1, Stevens Institute of Technology, Tuskegee University, and the University of Washington. The group includes private and public, residential and non-residential, and education-focused and research-focused institutions. It includes two Historically Black Universities, one Hispanic-serving university, and one all-women’s college. Combined, these eight institutions awarded 3,320 engineering baccalaureates in 2004 [2].

In this article, we collect baseline data on the current mechanical engineering curriculum by dissecting it into topics and subtopics. This baseline data permits us to study a number of issues, including what constitutes the core material presented at all or nearly all schools, the similarity of curricula at different institutions, and the impact of the ABET engineering criteria in shaping curricula.

1Unlike the other seven institutions, Smith does not have a mechanical engineering program but an engineering science program which allows students to specialize in mechanics by taking three or more electives in mechanics.
II. METHODS

We have chosen to dissect the mechanical engineering curriculum at a level much more finely grained than courses. We have compiled a list of the topics and subtopics required in the mechanical engineering curriculum, attempting to be as narrow and specific as possible. We began with our own institution, Johns Hopkins University, obtaining syllabi for the 20 required technical classes for a mechanical engineering B.S. degree: Calculus I, Calculus II, Calculus III, Physics I, Physics II, Introduction to Solid-State Chemistry, Freshman Experiences in ME, ME Computing, Statics and Mechanics of Materials, Mechanics-based Design, Mechanical Engineering Thermodynamics, Introduction to Fluid Mechanics, Heat Transfer, Design and Analysis of Dynamic Systems, Materials Selection, Capstone Design Project, Manufacturing Engineering, Engineering Business and Management, Linear Algebra and Differential Equations, and Dynamics.

We assume that faculty members include in course syllabi those topics which they consider to be essential for completion of the course. From the syllabi for these 20 required courses, we extracted 281 separate topics and subtopics. Thus, every student majoring in mechanical engineering at Johns Hopkins University is exposed to 281 technical and professional topics while earning a B.S. degree.

We then repeated the process using the syllabi for required courses for a mechanical engineering baccalaureate at eight other academic institutions—the seven other members of the project team plus the Massachusetts Institute of Technology (MIT). MIT was included because its comprehensive OpenCourseWare project ensured that the syllabi would be accessible on line and at a uniform level of detail; it is considered to be among the best programs in mechanical engineering (rated number one by US News and World Report); and it is a large producer of engineering bachelor’s, master’s and doctoral degrees [2].

The nine sets of curricula produced a list of 2,151 topics, but we were able to reduce the list to 1,392 in three steps. The first step was to eliminate identical listings: for example, acceleration in machines is required at two separate institutions.

The second step, a bit more challenging, was to resolve differences in the use of terminology. There were several cases of the same topic with two different names. For example, the first list contained anti-differentiation and integration. We retained the more common term, integration, and eliminated the less common one. Similarly, we retained harmonically excited systems, and deleted free/forced response to harmonic excitation.

The third step was to determine how distinct from each other topics need to be in order to remain on the list. As two examples, consider external flow/airfoils, and natural modes/modal analysis. As a practical matter, airfoils are the primary example of external flows studied by students and engineering professionals, but external flow could mean flow of a liquid over an object rather than flow of air over a solid; therefore, in this particular case, we left external flows and airfoils as separate topics on the list. By contrast, natural modes and modal analysis were judged to be sufficiently similar to be combined. They differ in that modal analysis refers more broadly to expansion of dynamic behavior using natural modes as the basis vectors.

Although it contains both broad and narrow entries, the topic list is an informative baseline and is thought provoking in what it tells us about the typical mechanical engineering curriculum currently in place at U.S. colleges of engineering. The frequency of occurrence of each topic is particularly significant. In the next section of this article, we present the frequency data. We use this data to study three important questions: (1) What is the body of knowledge (BOK) that defines mechanical engineering undergraduate degrees? (2) How much do mechanical engineering degree programs differ from each other? (3) What role do the ABET engineering criteria play in defining mechanical engineering curricula?

III. FREQUENCY DATA: DEFINING THE BOK

Table 1 includes alphabetical lists of all topics which were listed as required by at least three of the nine institutions whose syllabi were examined.

In addition, 162 topics were required at only two institutions, and another 769 topics were required at just one. Table 2 is an alphabetical list of all topics which were listed as required by the majority of the nine institutions whose syllabi were examined. Five or more institutions constitute a consensus.

There are several interesting points that emerge from Tables 1 and 2. First, it is possible to consider the consensus list in Table 2 as defining the Body of Knowledge which undergraduates in mechanical engineering need to master. These topics define what is currently taught, not necessarily what should be taught. However, they form a baseline for assessment of the mechanical engineering curriculum of the present and the future.

Other disciplines have attempted to define a BOK. The most well known is American Society of Civil Engineers’ (ASCE) “Civil Engineering Body of Knowledge for the 21st Century,” released in February 2004. The BOK is defined as the knowledge, skills and attitudes necessary to become a licensed professional civil engineer, based on ASCE Policy Statement 465 for making the master’s degree a prerequisite for practice of civil engineering [10].

The American Society of Mechanical Engineers (ASME) Board of Engineering Education formed a BOK Task Force in June 2003, and ASME has completed a BOK for one specific area: the Engineering Management Certification. Completed in 2004, it lists eight domains with 49 knowledge areas and 170 sub-knowledge areas [11].

Second, the topic frequency information is a useful catalyst for curricular reform. It is as significant for what is absent as for what is present. For instance, the following do not appear on the list of topics required at a majority of the schools surveyed: bearings, biotechnology, boundary layer flow, continuity, debugging, flexure, rotational motion, shafts, thermochimistry, and trusses. On the other hand, some faculty on the team were surprised that refrigeration, sketching and curves made the list of topics required for every mechanical engineering major.

A reasonable question to ask is whether the consensus list reflects the material which we, as a community, wish to regard as the BOK essential to students graduating with a baccalaureate in mechanical engineering. If the answer is no, we must closely examine those topics we think should not be included in the list and those topics which we believe should be included but are missing.

Third, the consensus list spells out what elements comprise today’s mechanical engineering curriculum. It includes specific technical topics which have traditionally fallen into the mechanical
engineering domain, such as gears and refrigeration. There are topics which are identifiable as the fundamental science (mostly physics and mathematics) that is generally required for mechanical engineering students. Some topics on the ME consensus list are more traditionally related to other engineering disciplines: for instance, circuits, electricity, magnetism and optics seem more the domain of electrical engineering than mechanical. There are topics that relate more to the profession of engineering than to technical disciplines,

Table 1. List of topics appearing in three or more of the nine institutions by frequency of occurrence.

<table>
<thead>
<tr>
<th>Required by nine:</th>
<th>conduction, convection, design methodologies, economics, first law of thermodynamics, gases, harmonic motion, second law of thermodynamics, vector operations</th>
</tr>
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<tbody>
<tr>
<td>Required by eight:</td>
<td>CAD/CAM, circuits, conservation laws, integration methods, linear differential equations</td>
</tr>
<tr>
<td>Required by seven:</td>
<td>electromagnetism/electricity, ethics, friction, kinematics and dynamics of rigid bodies, Laplace transforms, optimization, radiant heat transfer, refrigeration, stress and strain of deformable bodies, Taylor series</td>
</tr>
<tr>
<td>Required by six:</td>
<td>atomic physics, beam theory, bonding, capstone design project, ceramics, communication, data analysis, derivatives, entropy, the environment and industrial ecology, Fourier series and integrals, frequency response, impulse and momentum, kinematics and dynamics of particles, limits, metals, Newton’s laws, optics, polymers, sketching, torsion</td>
</tr>
<tr>
<td>Required by five:</td>
<td>combustion, control volume analysis, creep, dimensional analysis, equilibrium, fluid properties, gears, geometry (solid analytic), ideal and real gases/vapors, internal combustion engines, multiple integration, operational amplifiers, periodic table and the elements, polar coordinates, project management, stability analysis, statistics, stoichiometry, transfer functions, waves, writing</td>
</tr>
<tr>
<td>Required by four:</td>
<td>bearings, boundary layer flow, columns, conservation of energy, continuity, costs, debugging, equilibrium of rigid body systems and subsystems, feedback control, flexure, fluid mechanics, free body diagrams, fundamental theorem of calculus, gas laws, gas turbines, heat exchangers, infinite series, Kirchhoff’s laws, lab practices/safety, laminar flow, line integrals, linkages, matrix operations, mechanics, modal analysis, Mohr’s circle, probability, pure substances, rotational motion, semiconductors, series, shafts, similitude, springs (mechanical), thermochemistry, tolerances, trusses, turbulent flow</td>
</tr>
<tr>
<td>Required by three:</td>
<td>aesthetics, angular momentum, arrays and lists, atomic properties of materials, bending, Bernoulli equations, Bode plots, boiling, brakes, buckling, columns, earing, chemical reactions, combined loading, complex numbers, compounds, condensation, control systems, Coulomb friction, crystalline materials, decision making, design for manufacture, design of mechanical systems and mechanical elements, dimensioning, eigenvalues, eigenvectors, electrical and electronic components, electrochemical cells, energy, error analysis, fastener design, fatigue, finite element analysis, fins, fluid flow equations, force analysis, functions of several variables, Green’s theorem, harmonically excited systems, hydrostatics, improper integrals, internal forces, irreversibility, joining, lift and drag, linear momentum, Navier-Stokes equations, numerical analysis, oxidation, phase equilibrium, profession of engineering, quantum mechanics, Rankine cycles, root locus, second order systems, sensitivity analysis, solid modeling, sound, Stokes’ theorem, strengthening mechanics and processes, stress concentrations, stresses from shearing forces, surface integrals, teamwork, tension, time domain analysis, viscous flow, visualization, welded joints, work and energy</td>
</tr>
</tbody>
</table>

Table 2. Consensus list of topics at the majority of the institutions.

| Required by five or more: | atomic physics, beam theory, bonding, CAD/CAM, capstone design project, ceramics, circuits, combustion, communication/writing, conduction, conservation laws, control volume analysis, convection, creep, data analysis, derivatives, design methodologies, dimensional analysis, economics, electricity/electromagnetism, entropy, equilibrium, ethics, first law of thermodynamics, fluid properties, Fourier series and integrals, frequency response, friction, gears, geometry (solid analytic), harmonic motion, ideal and real gases/vapors, impulse and momentum, integration methods, internal combustion engines, kinematics and dynamics of particles, kinematics and dynamics of rigid bodies, Laplace transforms, limits, linear differential equations, metals, multiple integration, Newton’s laws, operational amplifiers, optics, optimization, periodic table and the elements, polar coordinates, polymers, project management, radiant heat transfer, refrigeration, second law of thermodynamics, sketching, stability analysis, statistics, stoichiometry, stress and strain of deformable bodies, Taylor series, the environment and industrial ecology, torsion, transfer functions, vector operations, waves |

Note that this list contains only 64 topics, just 4.5 percent of the total.
such as ethics, project management, and writing technical reports, prescribed by ABET engineering criteria and sometimes called the “professional skills” as opposed to the “technical skills.” The most specific topics on the list are the technical skill topics traditionally found in the mechanical engineering domain. The professional skill topics, such as communication and ethics, are far broader. Yet the professional skills should be taught and can be taught as effectively as the technical skills [12, 13].

Fourth, a very significant characteristic of the core curriculum in mechanical engineering as pictured in the frequent topic list is that it is easily handled in a degree program of four years or even less. As in much of engineering, degree programs in mechanical engineering average significantly more than four years for a baccalaureate [14]. Many faculty members insist that the explosion of technical knowledge requires the addition of more material to the curriculum, resulting in a curriculum requiring more than four years to complete [10]. However, if the topic list is an indication of consensus topics that all ME students must see, then it is conceivable to craft a very efficient curriculum by whittling down much of the material in topics not making the frequent topics list, ie, those topics required at four institutions or fewer. This is a controversial suggestion but one worth discussing. With tuition costs rising rapidly, and the financial aid need of engineering students nationwide exceeding that of students in the arts and sciences, a reasonable question is what the balance should be between efficient education and technologically complete education. The frequent topic list supports the opinion that we have significant room to move on to the efficiency side of this argument [14–16].

For example, calculus is often considered a stumbling block or gatekeeper course [17, 18]. The institutions in our survey require three or four semesters of calculus. While calculus is the language of engineering [19], are all calculus topics typically presented by mathematics departments necessary for mechanical engineers? Our high frequency list indicates that integration methods, Taylor series, derivatives, limits, and polar coordinates are essential; but calculus topics on the low frequency list—conics, Cramer’s rule, l’Hospital’s rule, and transcendental functions—are worth a second look. These topics are required by only one institution of the nine, and the advantage of a more efficient degree program may dictate that they be dropped from the ME canon.

Computing science is also of interest. While eight of the nine institutions surveyed require at least one computing course, there is a wide variety in topics they cover. CAD/CAM is required by eight schools, data analysis by six, and some sort of programming by six; beyond that there is no consensus. Two institutions require basic computer use, two require computer architecture, four require debugging and two require every ME major to learn Fortran. Among the computer topics required at the institutions surveyed are the following low-frequency topics: applets, classes and objects, derived classes, inheritance, mobile code, procedural abstraction and Web e-mail. These appear on the lists of topics required at only one or two institutions of the nine.

Fifth, the list of 64 essential topics also provides a means of determining the relative weight of various categories of learning currently applied to mechanical engineering undergraduate degrees. Based on the number of topics, the current mechanical engineering curriculum is 45 percent engineering, 18 percent mathematics including calculus, 15 percent physics, 12 percent chemistry, four percent computer science, two percent communication, two percent statistics, one percent economics, one percent ethics, and zero percent biology.

These statistics indicate a good balance between engineering topics on the one hand, and mathematics, physics and chemistry topics on the other, but one must ask whether they are connected and integrated together [7, 8]. Fordy and Ohland note that today’s curriculum has solid foundations in science and mathematics with the expectation that students connect mathematics and science concepts to engineering practice, but freshman attrition as well as feedback from students suggest that the relationships among mathematics, engineering, and science have not been clearly communicated through science-based curricula [20]. Dally observed that at his university, engineering faculty teach only 26 percent of the curriculum in the freshman and sophomore years and this is recognized as a common problem in undergraduate engineering programs [3].

Sixth, an examination of the topics which we found at all nine schools may tell us something about the nature of the historical ME curriculum. The topics which we found at all nine schools were: conduction, convection, design methodologies, economics, first law of thermodynamics, gases, harmonic motion, second law of thermodynamics, and vector operations. Of these nine topics, five relate to heat transfer and thermodynamics, two to design, one to the general area of dynamics, and one to mathematics. These nine universal topics constitute a heavy slant toward the thermodynamic fields, reflecting ME’s classical origins in mechanics (seventeenth and eighteenth centuries) and thermodynamics (nineteenth century). However, the discipline’s contemporary interests indicate that the profession is changing from “the branch of engineering that encompasses the generation and application of heat and mechanical power and the production, design, and use of machines and tools” to “one that addresses societal concerns through analysis, design, and manufacture of systems, at all size scales” [15].

The mechanical engineering community can use the topic lists as a baseline to discuss how things might change in light of interdisciplinary collaboration and the development of new technologies. The most popular areas for expansion of engineering programs and for research dollars over the recent years have been biotechnology, nanotechnology, materials science and photonics, information and communications technology, and environmental engineering [21, 22]. Paradoxically, these popular areas are hardly mentioned among the topics most commonly found in mechanical engineering curricula. Does this confirm a view that the mechanical engineering curriculum is too traditional and not forward-thinking enough? Should the trends in technical research and engineering degree programs find their way into mechanical engineering degree programs more rapidly? If the ultimate goal of revising the program is to attract larger numbers of better students, and to produce degree recipients more prepared for the jobs of the future, then it is hard to argue that the trends in funding and program growth should be ignored. For instance, there is currently nothing clearly biological on the topic consensus list. With the growing trend toward a biological focus in science and engineering [22–24], mechanical engineering faculty might do well to consider whether there are biological topics that ought to be on the high frequency list in the future.

IV. PROGRAM SIMILARITIES AND DISSIMILARITIES

By simply considering course titles one might get the impression that there is little difference among mechanical engineering degree
Most ME departments, based on our sample, require the following courses: Calculus I, Calculus II, Calculus III, Physics I, Physics II, Statics, Mechanics, Materials, Design, Thermodynamics, Fluid Mechanics, Heat Transfer, Manufacturing, Differential Equations, Dynamics, Instrumentation/measurement, Systems, and a Capstone Design Project. However, on the topical level, we find that there is less in common than on the course level. This is shown by the relatively small fraction of topics (roughly five percent) which appear on the consensus list. There is a core of material which all schools cover, but there is also variation in what topics are added to the core. By examining the required topics of each institution, we can observe what makes each one unique. We list this in Table 3 without identifying the institutions. Our cohort shows a variety of characteristics, and the characteristics can be different from the perceptions which the institutions have of themselves.

As an example, consider institution A. Its mission statement refers to bringing the benefits of research to the world, tackling society's thorniest challenges, and the role of philanthropy in fueling scientific advancements. The topics in its ME syllabi indicate a program which is heavy on business and management topics, emphasizes linear algebra, is very heavy on computing, and pays short shrift to ethical considerations. Required courses do not list ethics or societal issues even once. Thus, the mission and reality seem to be at odds.

By contrast, consider institution B. This school's Web site states that "Engineering is about creating solutions for human needs." It emphasizes the linkage of science and the humanities, and warns against the pitfalls of overspecialization. Its curriculum is explicitly concerned with the environment, ethics and society, and stresses oral and written communication. Institution B’s syllabus topics match the image it wishes to project very well.

In some cases, there is a significant disconnect between what is defined as the institutional niche and the reality of what topics are required. This is probably the result of unconscious curriculum "creep," rather than deliberate consideration of the whole program and its components. To the extent that the topic list facilitates a reality check—an analysis of the distance between course topics and program mission—it is a useful exercise. It suggests that some institutions need to bring their required topics and their missions into alignment. More syllabi are appearing on the Web, and prospective students can peruse them in detail before deciding which school to attend. Thus, it is important to match course content and school mission, in addition to fulfilling the ABET engineering criteria.

### V. ABET Influence

In engineering in general, there is a tight coupling between curriculum and ABET engineering accreditation. ABET's criteria for engineering accreditation reflect the thinking of the engineering professionals and academics who comprise its voting members. The ME curricula reflect the importance of having accredited programs. The consensus list permits us to consider the extent to which the
two are coupled. To what extent do the BOK topics which appear in Table 2 map directly into the ABET engineering criteria? How commonly are ABET engineering outcomes found on the consensus list?

The eleven outcomes (Criterion 3) which apply to all engineering programs are as follows:

(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 within realistic constraints such as economic, environmental, social, political, ethical, health and safety, manufacturability, and sustainability;
(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;
(h) the broad education necessary to understand the impact of engineering solutions in a global, economic, environmental, 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 [25].

Shuman, Besterfield-Sacre, and McGourty divide Criterion 3 into the five technical skills: a, b, c, e, and k; and the equally important professional skills: d, f, g, h, i, and j. The professional skills are important because of rapidly changing technology, corporate downsizing, outsourcing, globalization, student and professional mobility, and the social imperative [13]. Their importance has been stressed repeatedly at ASME international conferences [15].

Let us consider the general outcomes one at a time:

Outcome (a): Application of mathematics, science, and engineering relates to almost every topic on the high frequency list.

Outcome (b): Data analysis is on the consensus list or BOK, specifically required by six of the nine institutions we surveyed.

Outcome (c): Design methodologies are required by all nine of the institutions surveyed. They require design in two or three different courses. This emphasis reflects the pre-2000 engineering accreditation requirement for a specific number of credits of design content, the ABET engineering outcomes, and numerous other recommendations for design in the engineering curriculum [26–31].

Outcome (d): Only three of the nine institutions require teamwork as a specific topic. One examines teamwork in a freshman engineering course, one in a product engineering course, and one in a senior project. Six institutions require capstone design projects, which may involve multi-disciplinary teams. However, merely requiring students to work on teams is not the same as structuring cooperation among them or providing instruction in team dynamics [32]. A study at the University of Nebraska at Lincoln found that although team projects were assigned frequently, only half the students received any training in teamwork, and most did not know the purpose of teamwork or the characteristics of an effective team [33]. Mismanagement of teams can have negative consequences, especially for women and minorities [34].

Outcome (e): Only one institution in our cohort lists problem solving as a specific required topic, but all nine require capstone design project, project management, or both.

Outcome (f): Seven out of the nine schools list ethics on required course syllabi. Two schools require entire courses; five require ethics as part of other courses, particularly design; and two institutions do not list ethics in any required course syllabus.

Five of the nine schools list topics relating to professional responsibility, including government regulations, insurance, legal issues, and professional registration. Responding explicitly to ABET engineering criterion 3(f), one institution requires a full course called Ethics and Professionalism in Engineering.

Outcome (g): Communication appears on the high frequency list, required by six institutions, but the emphasis is on writing. Five schools require technical writing or writing engineering reports (one school requires an entire course in technical writing), but only two of the nine institutions require oral communication skills. Students in all nine schools may be required to present oral reports, but it seems that only two of the institutions in our cohort actually teach oral communication skills.

Outcome (h): Only three schools list the topic impact of engineering on society. However, six institutions deal with ecological and environmental concerns as part of their design courses and materials courses.

Outcomes (i) and (k) are less about topical curriculum content than about the process of learning and do not lend themselves well to consideration here. We found no topics that map directly into these two outcomes.

Outcome (j): Only one institution lists the topic contemporary issues in technology and society or clearly associated topics.

Taken together, most of the eleven outcomes are achieved with clear topics in a majority of the schools in our study, but not all schools achieve all eleven outcomes with topics mapped specifically to them. While there is a strong correlation between ABET engineering criteria and the topics we found, the coupling is not perfect. The coupling is strong for outcomes a, b, c, e, and f (all technical skills except for f). It is weaker for outcomes d, g, h, and j (all professional skills).

In addition to the general outcomes which apply to all engineering programs, the specific requirements for mechanical engineering programs are:

The program must demonstrate that graduates have: knowledge of chemistry and calculus-based physics with depth in at least one; the ability to apply advanced mathematics through multivariate calculus and differential equations; familiarity with statistics and linear algebra; the ability to work professionally in both thermal and mechanical systems areas including the design and realization of such systems [25].

The requirements for mechanical engineering are worded broadly, with the exception of the requirement for familiarity with statistics and linear algebra, and Table 2, our high frequency or BOK list, does include statistics and linear differential equations.

VI. CONCLUSION

In this section we use the topic analysis to draw conclusions and support opinions on the direction mechanical engineering curriculum reform should take in the future.

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The frequency topic list defines what is currently taught by our cohort and not necessarily the ideal. It is a useful baseline for assessment and discussion about the mechanical engineering curriculum of the present and the future—a mechanical engineering body of knowledge.

The course syllabus is a useful document for assessing curriculum, particularly with the spread of open courseware, because it serves as an agreement between instructor and student. It is not enough to speculate that a topic is covered "somewhere in the curriculum." The topics which faculty consider important are included in their syllabi.

We found that there is less in common among institutions than we expected, shown by the small fraction of topics (roughly five percent) which appear on the consensus list. There is a core of material which all schools require, but there is also much variation in what topics are added to the core. This indicates that the core curriculum in mechanical engineering can be handled in four years or less. It should be possible to craft an efficient curriculum by eliminating many of the topics on the low-frequency list (Abbe errors, alpha prototypes, apples, arithmetic logic unit, availability, etc). We believe that the mechanical engineering curriculum would benefit greatly from such a cleansing of the curriculum, as it would leave greater flexibility and more time for more contemporary technical topics and professional skills. We believe that it would also attract students who currently avoid the field because of the perception that it would require extra time in college—something they can ill afford.

Eliminating "legacy" topics will make room for new ones arising from the interdisciplinary foundations of engineered systems, the rapid emergence of new technologies, and the convergence of biology and engineering. It is surprising and disturbing that the current BOK (Table 2) contains physics and chemistry topics, but no biological topics whatsoever.

The topic lists further demonstrate that although ABET engineering outcomes are closely linked to the mechanical engineering curricula across the nation, the match is not perfect. ABET engineering criteria are viewed seriously, but those that we found least clearly addressed were those least technically related, namely, the professional responsibilities area.

Thus, there is a need to strengthen the professional skills in the mechanical engineering curriculum: teamwork, ethics, communication, the impact of engineering on society, and knowledge of contemporary issues. These are vital because of today’s eclectic, constantly changing work environment, calling for astute interpersonal skills and engineers whose skills “extend well beyond the traditional science-focused preparation that has characterized engineering education since World War II” [35].

The syllabi we surveyed list the professional skills in an uneven way. All the institutions require team projects, but only three provide instruction on what constitutes an effective team. Most of the institutions we surveyed provide some instruction in writing, but not in oral communication. Those who do not currently require ethics should add a specific ethics component. It is not enough to speculate that ethics is brought up “somewhere in the curriculum.” We reiterate our assertion that if it does not appear on a syllabus, the topic is viewed as relatively unimportant by the faculty.

The topic information permits us to characterize an individual degree program by its dissimilarities from the core. When we did this we found some discord between perceptions of a program and the reality of topics taught. This suggests that the exercise of reviewing the curriculum topic by topic and aligning it with the mission of the program is long overdue. The mismatch between mission and reality is a symptom of the dangers of conducting curriculum reform in a piecemeal fashion. Instead, we suggest that all programs review their entire degree program content to ensure that the intentions of the program are reflected in its implementation.

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