Core Elements of an Undergraduate Biomedical Engineering Curriculum – State of the Art and Recommendations

Robert A. Linsenmeier[1] and David W. Gatchell[2]

***Abstract* – The goal of this work is to identify elements of the undergraduate biomedical engineering (BME) and bioengineering (BE) curriculum that should be common across universities. We approached the definition of a core curriculum in two ways. First, we are using the Delphi method to survey representatives of industry and academia to identify the concepts that all graduating bioengineers should know. Second, we analyzed the 37 ABET accredited BME and BE programs in the US to determine which courses are required for graduation. While no two programs are the same, certain courses are required by at least 75% of the programs and can functionally be regarded as the core at this time. Delphi study data suggest that the core should contain a few additional courses. Beyond courses required for all students, the accredited programs allow 18.2 ± 9.6 credit hours for specialization courses. Thus, while the BE major is broad, it is possible to insure that students obtain depth.**

Index Terms – Bioengineering curriculum, biomedical engineering curriculum, core content

INTRODUCTION

As of Spring 2006 there are thirty-seven undergraduate programs in biomedical engineering and bioengineering accredited by the ABET (www.abet.org) in the US, but there is no documentation on how similar or different these programs are, and it is therefore not clear whether there is a core undergraduate curriculum or not. Though industry's appreciation of bachelor's degrees in biomedical engineering degrees has grown, our interactions with industry professionals indicate that many in industry are still confused about the capabilities of bioengineers. We suggest that defining part of the curriculum as a common core would be beneficial to the identity of the field and for clarifying the skills of graduating bioengineers for industry [1]. One of the goals of the VaNTH (Vanderbilt-Northwestern-Texas-Harvard/MIT) Engineering Research Center in Bioengineering Educational Technologies is to define curriculum in this field. This paper describes the curriculum in its present state, which is itself useful for recognizing areas of similarity and difference across programs. It shows that a common core of coursework can be determined, and to a significant extent already exists. This work will be reported in a more complete form elsewhere [2].

METHODS

We analyzed the frequency with which particular courses are *required*, not simply offered, at 35 of the 37 currently ABET-accredited bioengineering programs. In some cases the curricula at established institutions are changing, so we attempted to use the most current data from the websites of the universities studied. Two programs were not included in the numerical analysis: Brown University gives a general engineering degree with a specialization in bioengineering, and Worcester Polytechnic Institute has a flexible curriculum that could not be mapped onto the same framework as the others. Courses were converted to a common base of semester credit hours when necessary. We were most interested in required engineering courses and biology courses, making the assumption that math, physics, and basic chemistry are relatively uniform across programs. In most cases an engineering course could be counted easily in a particular category, but in a few cases it was necessary to divide the credit hours for a course between two categories, for instance between our categories of thermodynamics and transport. Universities also often have courses that are required of all students, but which did not fit in our main categories. Courses in this "other" category include ethics, communication skills, economics, and professional development. Such courses comprise 7.8 ± 4.8 credit hours, which is a small fraction of the total hours of required courses. Most programs also have coursework that students take only if they are in a particular specialization of the major. It was important to keep track of the curricular time devoted to this category, but because we were interested in obtaining information about the core, we did not analyze the courses that fit in specializations and are only taken by a subset of the students.

We are also using the Delphi method to survey representatives of industry and academia to identify the concepts that are most relevant for all graduating bioengineers to know. Results of the first phase of this study are available at www.vanth.org/curriculum, and this information has been incorporated into our recommendations.

[1] Biomedical Engineering Department and Department of Neurobiology and Physiology, Northwestern University, Evanston, IL, r-linsenmeier@northwestern.edu
[2] Biomedical Engineering Department, Northwestern University, Evanston, IL, d-gatchell@northwestern.edu

RESULTS

The percentage of accredited programs that require one or more courses in important areas was calculated. At least 75% of programs require courses in physiology, biology other than physiology, mechanics, circuit analysis, computing, materials science, instrumentation, and statistics; 71% of the programs require a course in transport phenomena, including some balance among fluid mechanics, heat transfer and mass transfer. The only other courses required by more than 50% of programs are thermodynamics and signal analysis. Modeling, control theory, and organic chemistry fell in the range of 25 to 50%, and imaging was required at 20% of programs. All but two programs also require at least one definable design course, and the others must have ample design experiences integrated into their other courses in order to be accredited. Functionally, we consider the ones exceeding 70% to comprise the core of biomedical engineering at the present time. Programs differ in whether each of these courses is taken in the bioengineering department or outside of it. Design, mechanics, physiology and instrumentation are generally taught in BME, while computing, circuit analysis, and statistics are not.

A further analysis was done to determine the amount of time that each university requires in each of the subjects analyzed. We found that for those universities requiring a course, most of the required subjects take an average of 3 to 4 credit hours, or the equivalent of one course, although the standard deviations are sometimes large. For instance, statistics occupies 2.67 ± 0.63 credit hours (n=27 schools), and instrumentation occupies 4.25 ± 1.7 hours (n=27). The only courses that occupy substantially more time in the required curricula, closer to two courses, are the ones that are also required at the largest fraction of schools: mechanics 6.4 ± 2.85 (n=31 schools), design 6.21 ± 2.53 (n=35), physiology 5.89 ± 2.23 (n=34), and biology other than physiology (5.69 ± 2.5 n=31). While these topics are very commonly taught, again note the large standard deviations. After accounting for all other required courses, the curricular time left for engineering and bioengineering specialization courses is 18.2 ± 9.6 credit hours.

RECOMMENDATIONS

Based on the analysis above, as well as on information from the VaNTH Delphi Study of Key Content [3,4], we can make recommendations for the content of a biomedical engineering core. We imposed a limit of 78 credit hours for the core, allowing 18 hours of flexibility in specialization courses. Engineering, math and science then comprise 96 credit hours, three quarters of a typical 128 hour curriculum. Our prototype curriculum encompasses two years of math and a year each of physics and chemistry. It also includes all the topics that are covered by more than 70% of the programs at present. One course is recommended in each of those subjects, except biology, physiology, and design, where two are recommended. Within the 78 units we also recommend two of the following three courses: signal analysis, organic chemistry, and thermodynamics. We prefer to recommend all three, but this does not fit, unless a program chooses to reduce the specialization category.

Bioengineering curricula tend to have more math and science than required by ABET standards, and somewhat less engineering. In order to meet the ABET guideline of a minimum of 1.5 years of engineering topics, it will be necessary that a university teach about a third of the credit hours in thermodynamics, physiology, computing, and statistics in such a way that they are engineering courses, which should not be difficult.

DISCUSSION AND CONCLUSIONS

The analysis of curriculum shows that there is already functionally a core of material taught by a large number of biomedical engineering programs, so moving to a somewhat more uniform core would not be too difficult for biomedical engineering programs. The prototype we have suggested includes the topics that should allow biomedical engineers to successfully pursue any area of the field. However, we recognize that listing course names is not as valuable as specifying the concepts to be covered. For this reason, the core curriculum will remain incomplete until the Delphi Study [4] has been completed. Results from the first round of the Delphi Study, however, show that there is strong agreement between the topics judged to be important by academia and industry and the courses we recommend in the core. These concepts are posted on the VaNTH Curriculum website (www.vanth.org/curriculum).

The basic engineering courses recommended in this curriculum are traditional, at least in name. They are not focused on the exciting new research topics that academic bioengineers often engage in. This is a reflection of our assumption that traditional engineering topics are still required to provide both conceptual and analytical foundations for further study. The newer areas would provide examples or problems to be included in these fundamental courses, and of course would be covered in specialization courses taken beyond the core.

No branch of engineering turns out graduates that are homogeneous across institutions. However, each starts with a core set of knowledge and skills that are widely recognized as attributes of their graduates, and then builds on that foundation. A core provides clarity to industry, and different programs can then promote their graduates on their individual strengths. The core we propose is broader than is typical in other engineering fields. In the past, breadth, which was assumed to be incompatible with depth, was sometimes considered to be a weakness of biomedical engineers. However, at least some industries now appear to view the breadth of biomedical engineers as a strength. There are at least two reasons for this. First, medical systems are often multifaceted, and second, biomedical engineers are often placed in positions where an important part of their value is knowledge of applied biology and their ability to speak to different kinds of engineers and to medical practitioners.

ACKNOWLEDGMENTS

We thank Dr. Thomas Harris and Mr. David Lipps for their assistance. This work was supported primarily by the Engineering Research Centers Program of the National Science Foundation under Award Number EEC-9876363.

REFERENCES

[1] Linsenmeier, R.A. What Makes Biomedical Engineer? Defining the Undergraduate Biomedical Engineering Curriculum. ***IEEE Engineering in Medicine and Biology*, 2003, *22(4)* 32-38.**

[2] Gatchell, D.W., Harris, T.R. and Linsenmeier, R.A. Biomedical Engineering Undergraduate Core Curriculum: Current Practice and Recommendations, submitted for publication.

[3] The Delphi Method. [Online] http://www.iit.edu/~it/delphi.html.

[4] Gatchell, D.W., Linsenmeier, R.A.; Harris, T.R.. Biomedical Engineering Key Content Survey – The 1st Step in a Delphi Study to determine the core undergraduate BME curriculum. *Proceedings of the 2004 American Society for Engineering Education Annual Conference & Exposition*. American Society for Engineering Education, 2004. http://www.asee.org/acPapers/code/getPaper.cfm?paperID=7253