Biomedical Engineering Key Content Survey – The 1st Step in a Delphi Study to determine the core undergraduate BME curriculum

David W. Gatchell[1,4], Robert A. Linsenmeier[1,2,4], Thomas R. Harris[3,4]

Departments of [1]Biomedical Engineering and [2]Neurobiology and Physiology, Northwestern University/[3]Departments of Biomedical Engineering, Medicine, and Chemical Engineering, Vanderbilt University/[4]VaNTH Engineering Research Center

The field of Biomedical Engineering has seen marked growth over the past ten years. In fact, since 1990, we have witnessed a two-fold increase in the number of undergraduate programs granting degrees in Biomedical Engineering with continued growth expected[1,2]. A concomitant need that has materialized with this increase is the development of a common curriculum of key concepts with which all biomedical engineers (BMEs) should be familiar as well as an "identity" that will aid industry in the hiring of undergraduate biomedical engineers[2,3,4]. As of now, many industrial representatives are hesitant to hire undergraduate BMEs because of uncertainty in a biomedical engineer's training as well as a perceived lack of expertise in any particular area of engineering[2,4]. BMEs also face the daunting task of convincing future employers that they are just as capable as their peers trained in other more established and "better defined" engineering disciplines[2,4]. These opinions imply that better communication is required between academia and industry as to the skills and abilities that undergraduate BMEs need and should bring to the workplace.

Others have attempted to determine the core elements of an undergraduate biomedical curriculum[1,5], but no one has delved to the depths that we feel are necessary for achieving a consensus set of topics[2]. One of the primary objectives of the VaNTH Engineering Research Center (ERC) for Bioengineering Educational Technologies[6] is to achieve this consensus. We believe that it is possible to identify topics, the "key content," that comprise the "core" of undergraduate programs in biomedical engineering. It is expected that all biomedical engineers will be familiar with these "key topics" by the time they graduate with Bachelor of Science degrees. We also feel that there are a set of "core competencies" (e.g., communications, teamwork, ethics, etc.) with which BMEs should be familiar, if not able to masterfully demonstrate. Though of equal importance to the "key content" knowledge described above, our present focus is on determining the key elements of biomedical engineering domain knowledge and disseminating these elements to our colleagues in academia and industry (other members of VaNTH are actively developing a consensus set of "core competencies" in collaboration with the CDIO[7] initiative at MIT).

Our procedure for determining this "key content" is to solicit feedback from biomedical engineering experts in academia and industry through a web-based survey that will proceed through several iterations, i.e., the Delphi method. Participants have the opportunity to evaluate whether individual topics should be included in a recommended list of "key content." The initial list has been derived from taxonomies generated primarily by VaNTH faculty. Successive iterations will be needed 1) to uncover more details about the key content than will be feasible in the first round, 2) to obtain feedback on new ideas that arise in earlier round(s) and 3) to determine a level of proficiency expected of biomedical engineering students within each topic.

Overview of Survey

The survey is comprised of eighty questions divided among nineteen categories including eleven biomedical engineering domains, four biology domains, physiology, engineering design, and mathematical/scientific pre-requisites. Within each category we ask the participant to assess his own level of expertise for that topic, after which, he is asked to assess the importance/relevance of several concepts comprising that topic to a core curriculum that should be recommended for ALL undergraduate BME majors. In addition, participants have the opportunity to suggest concepts not included in the survey, but which should be included in a BME core curriculum.

The categories are as follows (number of questions/concepts in each category):

1. Personal Profile (4)
2. General Engineering Skills (3/9)
3. Design (3/8)
4. Biosignal and Systems Analysis (3/18)
5. Bioinstrumentation (3/12)
6. Bio-Optics and Photonics (3/9)
7. Medical Imaging (3/6)
8. Biomechanics (3/9)
9. Biothermodynamics (3/17)
10. Fluid Mechanics (3/11)
11. Heat and Mass Transfer (4/15)
12. Biomaterials (3/9)
13. Biotechnology (1/1)
14. Bioinformatics (3/9)
15. Physiology (20/50)
16. Biology (9/40)
17. Mathematical Concepts (4/15)
18. Pre- and Co-requisites (4/8)
19. Concluding Remarks (1)

For category 1, the survey participant is asked to provide a brief description of his current position, working environment, and experiences working within the field of Biomedical Engineering. For categories 2-18, the participant is given a list of concepts the domain comprises (note that the number of concepts is not equal to the number of questions – the majority of domain questions include multiple concepts). For each concept, we ask the participant to rank its importance/relevance (utilizing a six-step scale with a "no opinion" option) to a core curriculum in biomedical engineering recommended for *all undergraduate* Biomedical Engineering majors. In category 19, we simply provide some concluding remarks and solicit general feedback about the survey from the participant.

It should be noted that we did not explicitly list such important categories as "Laboratory Skills" and "Mathematical Modeling". Whereas mathematical modeling has been included within category 17 (we solicited feedback on nine modeling concepts), laboratory skills were not

considered an essential part of our "key content" survey. We argue that these skills are more "competency-based" than "content-based", and should be integrated with the core competency work mentioned above. In addition, what laboratory skills are expected of undergraduate biomedical engineers should directly correlate with what "content" they are expected to master, e.g., if biotechnology is not required of all students then mastery of the laboratory skills associated with this domain should not be either. Therefore, we feel it is prudent to postpone feedback on this topic until the "key content" is better defined.

Redundant Concepts and "Ringers"

As the participant progresses through the survey he will encounter concepts missing from one topic but that have been included in another, e.g., concepts that traditionally fall within both transport and thermodynamics. This was done to shorten the length of the survey. As a counterpoint, however, we have included some redundancies, i.e., similar concepts listed under distinct BME domains, in order to check for consistency in the participant's ratings. We have also added some advanced concepts ("ringers") to the survey in order to assess the participant's reliability. These "ringers" should be seen as too advanced for a core, undergraduate BME curriculum and rated low accordingly.

Participation

We have contacted over 1,000 academic and industrial representatives for participation in this survey. Our academic contacts represent all 25 ABET accredited programs[1] as well as many of the newly developed undergraduate and, as of yet, non-accredited BME departments in the United States (approximately 90). We also are relying heavily on the opinions of VaNTH faculty, having solicited the participation of 28 Northwestern University BME faculty, 14 Vanderbilt University BME faculty, and 14 University of Texas-Austin BME faculty. Our industrial participants have been solicited from various BME conferences and meetings (e.g., CUBIC[8]). The remainder of our participants is comprised primarily of young alumni from the undergraduate BME programs at Northwestern and Vanderbilt Universities, now working in industry.

In order to differentiate between the opinions of accredited programs and more recently developed departments, we have separated their responses for comparison. We anticipate a variation in focus for these two groups (i.e., older programs have traditionally emphasized ME, EE, and CE applications to physiology and medicine, whereas newly developed programs may stress domains such as BioMEMs, Bioinformatics, etc.) therefore, we will report their recommendations separately. In addition, we will also separate responses from industrial representatives and young alumni, as we anticipate a significant disparity in their responses compared to those submitted by academic representatives.

The above list of participants does not include medical students or graduate students in biomedical engineering. We did not focus on these groups for two reasons: 1) the motivation for this survey is to facilitate communication between academia and industry, in turn, increasing industrial opportunities for recent biomedical engineering graduates; 2) it has been argued that existing biomedical engineering programs already provide undergraduates the necessary training

for success in graduate and medical schools[2]. However, we have included representatives from medical schools and hospitals that hire undergraduate biomedical engineering majors. This inclusion is justified by the fact that the job responsibilities of such positions are primarily industrial in nature.

Future Work and Dissemination of Results

As mentioned in the introduction, we will be presenting results from the 1st round of our Delphi study. Future rounds of our study will use these results to expound upon concepts deemed "important" and to assign a level of proficiency to each concept. These proficiencies will act as learning objectives with the specific expectation (i.e., verb choice) chosen from either Bloom's or Biggs' taxonomies[9,10]. A similar approach has already been successfully utilized in the development of the CDIO syllabus[7] ("… a rational, complete, universal, and generalizable set of goals for undergraduate engineering education.") for undergraduate aerospace engineering majors at MIT.

One of the objectives of presenting this work at the ASEE conference is to disseminate our results to a wide audience of interested participants and to solicit feedback. In addition to presenting results at this conference, we anticipate presenting our results at other engineering conferences including those sponsored by the Biomedical Engineering Society (BMES) and the IEEE Engineering in Medicine and Biology Society. We will also be posting our results on the VaNTH curriculum website: http://www.vanth.org/curriculum/. Interested parties should reference this site for periodic updates as we present results from future rounds of our Delphi study.

One of the major challenges in utilizing survey results is determining the significance of the responses. As it now stands, we have used a six-point system (including the "no opinion" option) for assessing the significance of each listed concept and await feedback from the hundreds of young alumni, industrial representatives and academic biomedical engineers who have agreed to participate in our survey. We anticipate a bi-modal distribution in our results (i.e., those concepts which are rated as being "important" to "very important" to a consensus BME curriculum vs. those concepts which are rated as being of "low" to "very low" importance), but will have to also consider those concepts which are rated as having "moderate" relevance to the BME "key content" that we are attempting to ascertain. Perhaps, the sheer number of highly rated concepts will make this observation moot but it will, nevertheless, need to be addressed.

In summary, we expect that the results of this survey will aid academia in identifying the fundamental concepts that undergraduate BMEs should know and should facilitate the industrial hiring of a larger percentage of our undergraduates by further establishing the identity of the biomedical engineering field.

This work is supported primarily by the Engineering Research Centers program
of the National Science Foundation under annual grant EEC-9876363.

1. Whitaker Foundation. (January 14th, 2004). Biomedical Engineering Educational Summit Meeting, 2000. [Online]. Available: http://summit.whitaker.org.

2. R.A. Linsenmeier. "What Makes a Biomedical Engineer? Defining the Undergraduate Biomedical Engineering Curriculum". IEEE Engineering in Medicine and Biology, Vol. 22:4, pages 32-38. July/August, 2003." © 2003 IEEE.

3. R.A. Linsenmeier, T.R. Harris, and S. A. Olds. "The VaNTH Bioengineering Curriculum Project". Proceedings of the Second Joint EMBS/BMES Conference (CD-ROM, Omnipress): 2644-2645, 2002.

4. M.A. Friedman. Biomedical engineering education and industry: matching the product to the customer. IFMBE NEWS, No. 19, Jan. 1996. [Online]. Available: http://www.ifmbe.org/.

5. T.A. Desai, R.L. Magin. A cure of bioengineering? A new undergraduate core curriculum. J. Eng. Educ., vol.. 90, pp. 231-238, Apr. 2001.

6. VaNTH refers to a collaboration between **Va**nderbilt University, **N**orthwestern University, University of **T**exas, Austin and the **H**ealth Sciences and Technology Program between Harvard University and MIT.

7. http://www.cdio.org/.

7. B.S. Bloom. Taxonomy of Educational Objectives. New York: Longmans Green, 1956.

8. J.B. Biggs. Teaching for Quality Learning at University. London: Society for Research into Higher Education/Open University Press, 1999, pp. 33-51.

10. http://www.cubic-online.org/.

DAVID W. GATCHELL is a postdoctoral fellow in the Department of Biomedical Engineering at Northwestern University working under the guidance of Dr. Robert A. Linsenmeier. As a member of the VaNTH ERC, he works to identify the key content knowledge and core competency skills expected of undergraduate biomedical engineering majors.

ROBERT A. LINSENMEIER is the Bette and Neisen Harris Professor of Teaching Excellence at Northwestern University. He is in the Department of Biomedical Engineering, of which he served as chair from 1997 to 2002, and the Department of Neurobiology & Physiology in the Weinberg College of Arts and Sciences. Since 1999 he has been engaged in education research through the VaNTH ERC, of which he is Associate Director and leader of the Bioengineering Domain Thrust.

THOMAS A. HARRIS is the Orin Henry Ingram Distinguished Professor of engineering and professor of biomedical engineering, chemical engineering, and medicine at Vanderbilt University. He is currently the director of the VaNTH ERC.