VANTH: A CENTER FOR THE INTEGRATION OF BIOENGINEERING, LEARNING SCIENCE AND LEARNING TECHNOLOGY

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Abstract ¾ *The VaNTH Engineering Research Center in Bioengineering Educational Technologies is dedicated to the development of new approaches to bioengineering education. The center is a partnership among Vanderbilt University, Northwestern University, University of Texas at Austin and the Harvard/MIT Health Sciences and Technology Program (VaNTH). Through collaboration with learning scientists, we are developing new ways to formulate and deliver learning materials in bioengineering. The Center houses projects in basic learning science and technology that can be applied in bioengineering education at all levels, projects aimed at the development of new materials in the principal domains of bioengineering, projects on the formulation of new computing methods for course delivery and projects in the development of assessment methods for the effectiveness of these materials. New concepts stemming from psychology and neuroscience illuminating how people learn will under- gird the effort to develop new technologies.*

Index terms ¾ *bioengineering, learning science, learning technology.*

INTRODUCTION

The flagship program for engineering research supported by the U.S. National Science Foundation (NSF) is the Engineering Research Centers (ERC) program [1,2]. The programs are generally focused on a specific area of science or technology (e.g. biomaterials) and are expected to have basic research components, research leading to the development of enabling technologies and systems research aimed at creating a broad industrial or social impact. Support is substantial and amounts to about $2,000,000 per year for 8-10 years. Such awards are non-renewable and it is expected that the centers will emerge as independent, self-sustaining entities after the initial period. In 1998, NSF announced a competition for an ERC aimed at the development of bioengineering educational technologies. Eventually, this center was awarded to a group of partnering universities: Vanderbilt University (the lead institution), Northwestern University, the University of Texas at Austin and the Harvard/MIT Division of Health Sciences and Technology. This center has been active for about 18 months. It is called the NSF VaNTH (because of the institutions involved) ERC in Bioengineering Educational Technologies (subsequently this entity will be referred to simply as VaNTH).

VISION AND OVERALL STRATEGY

The task facing VaNTH was to design an educational system for bioengineering that would lay the foundation for the further development of this field as a science and as a profession. VaNTH defined its mission to be an ERC that would unite educators and engineers, in academia and industry, to define and develop bioengineering education for the future. Bioengineering lies within the intersection of biology with engineering, the physical/chemical sciences and mathematics. The future of bioengineering education, similarly, lies within an intersection. It is at the focal point of bioengineering, learning science and learning technology. Successful synergy promises an exciting new paradigm in bioengineering education for the 21st century. This promise offers the key to attracting the most talented and intellectually curious participants to the field of bioengineering, to shaping curricular frameworks which are knowledge centered, learner centered, assessment centered, and community centered, and to advancing the state of the art in learning technology and bioengineering. Thus, the mission of the ERC is to innovatively provide students of the next generation with knowledge in bioengineering so they may address some of the most demanding issues facing our society.

The overall strategy of the VaNTH ERC is to help create a new system of bioengineering education that will allow the field to respond to immediate and future challenges. The features we envision for this new educational system are as follows:

- Taxonomies of knowledge in bioengineering will have been developed and will be maintained through professional and scientific organizations that take responsibility for this task and rely broadly on peer review. These taxonomies will explicitly identify the relationships among biology, engineering and bioengineering subjects.
- Curricular pathways to and through the taxonomies will be developed and driven by goals for characteristics, knowledge and skills desired in graduates. In the U.S.A. these curricular criteria will be based on Accrediting

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- Board for Engineering and Technology (ABET) principles at the undergraduate level, but will explicitly deal with requirements, choices and alternatives to achieve these criteria. A system will exist in which dialog will occur among key constituents in a continuing manner regarding the appropriate curricula for bioengineering in all its forms. The effectiveness of these programs will be measured by sound evaluation methods.
- Structures and methods will exist in institutions of higher education to integrate knowledge and techniques from learning sciences, learning technology and bioengineering domains so that curricula, domain knowledge and teaching methods can produce effective education in bioengineering. Graduate programs will include education in these concepts for potential faculty members. Systems of evaluation and faculty reward will incorporate activity and research in teaching and learning more fully than currently.
- The value of learning technologies will have been demonstrated, and structures and methods for further innovation and effectiveness testing will exist. Commercial vendors and technology developers will devote resources to refining these technologies because of their demonstrated impact and demand.
- A system will exist that will allow faculty and other content developers to produce modular instructional materials in bioengineering that can be broadly and inexpensively disseminated through commercial publishers or other means. This system will have appropriate compensation that ensures the continuous maintenance of these materials over time.
- Structures and methods will exist to provide outreach to industry for continuing education and staff renewal in bioengineering. Structures and methods will exist for industry to influence curriculum development and contribute to the education of their workforce.
- Structures and methods will exist to provide knowledge about bioengineering to pre-college learners in a manner that supports the basic needs of those curricula for introductory scientific knowledge.

RECENT ADVANCES IN BIOENGINEERING EDUCATION, LEARNING SCIENCE AND LEARNING TECHNOLOGY

State of Educational Programs in Bioengineering

Education in bioengineering has evolved since about 1960 to a current state where there are 22 undergraduate programs accredited by the ABET in biomedical engineering and bioengineering. Another 18 programs are accredited as biological systems engineering or biological engineering. These latter programs have emerged from agricultural engineering departments and tend to have a greater interest in food engineering and environmental concerns. About 170 graduate programs in bioengineering, biomedical engineering, biological engineering and biotechnology are listed in Peterson's Guide [3]. These programs represent a broad range in focus and institutional culture.

In December 2000, the Whitaker Foundation hosted a “Biomedical Engineering Summit Meeting”[4]. This meeting developed a body of material dealing with programs and curricula in biomedical engineering, including commentary on philosophy underlying curricular choices. Data regarding programs in bioengineering and biomedical engineering compiled by the Whitaker Foundation [4] show 62 programs at the bachelor’s level in the U.S., of which 37 were founded in the 1990’s. Another 71 Master’s level programs and 74 Ph. D. programs exist (of course, all levels of these programs are usually in the same departments).

Vanderbilt, Northwestern, Texas and Harvard/MIT, the VaNTH institutions, have pioneered in bioengineering education. Their programs have been active for over 30 years. This experience forms a core of knowledge in curriculum for the VaNTH ERC.

Learning Sciences

Much previous work has been recently summarized in a report from the National Academy of Sciences entitled “How People Learn: Brain, Mind, Experience, and School” by Bransford, Brown and Cocking [5]. Overall, research on expertise and learning suggests that the best designs for learning environments include at least the following features: (1) they are learner-centered in the sense that they take into account the knowledge, skills, preconceptions and learning styles of the learners; (2) they are knowledge-centered in the sense that they help students learn with understanding by thinking qualitatively, organizing their knowledge around "key concepts" or "big ideas" of the discipline, and understanding the conditions under which different aspects of their knowledge are applicable; (3) they are assessment-centered in the sense that they provide frequent opportunities for students to make their current thinking visible so that their understanding can be refined as needed (ideally this is done prior to summative assessments such as tests); (4) they are community-centered in the sense that they foster norms that encourage students to learn from one another, plus encourage faculty to do likewise.

Reviews of K-16 teaching practices--including those used in engineering and bioengineering education--reveal a picture showing many different teaching strategies [4,5]. These include courses that are (a) heavily lecture based (where students typically take notes in class); (b) partially lecture based coupled with a strong emphasis on problem solving exercises completed in class and as homework; (c) laboratory-based activities; (d) computer-based activities (e.g., using simulations), and (e) project–based (design).

Some of the teaching practices that are discussed in the literature are highly innovative and worth studying in their own right. Others leave considerable room for improvement.

But a major issue is: How does one systematically study the strengths and weaknesses of a wide variety of teaching practices? This becomes even more problematic when one realizes that there is a great deal of variation within categories such as "lecturing", "doing labs", having students work collaboratively, "teaching with simulations", and so forth.

One answer to this dilemma is to reframe the question. Research in the learning sciences [5] suggests that it is not useful to simply catalog the types of teaching strategies used in courses and attempt to answer the question "which teaching strategy is best?" (e.g. lectures versus labs versus simulations, etc.). The ideal teaching and learning strategy depends on the goals of the instructor, the levels of knowledge and skills of the students, and the particular materials being taught. Overall, the most important focus should be on processes of learning, not on teaching *per se*.

Technology Support for Learning

New technologies--including computers, CD ROMS, DVD, networking and Internet technologies--make it possible to utilize insights from learning theory to significantly enhance the quality of both student and faculty learning. Examples are briefly summarized below.

- <u>Bringing authentic problems into classrooms</u>: New technologies encourage problem finding and problem-solving by introducing authentic real-world problems on media. These interactive technologies make it much easier to search and explore complex cases relevant to areas such as medicine, biology, mathematics and, we hypothesize, bioengineering. Simulation environments can also introduce realistic problem situations. Simulations support a particularly active form of learning because students can manipulate the simulations and see the consequences.
- <u>Resources and tools to support problem solving</u>: In addition to introducing students to complex problems, technology serves as a scaffold for solving these problems by enabling them to seek assistance from outside the classroom, and by enhancing their work through the use of powerful tools. The World Wide Web (WWW) brings an enormous database of information into the classroom. These resources make use of hypermedia through which dynamic images, sound, and text can be seamlessly woven together and flexibly organized. When compared with text-based resources, electronic references are easier to search and to update[6]. Tools for problem solving include word processing, spreadsheets, visualization programs (e.g. CAD) and interactive simulations and programs for mathematical modeling (e.g. MatLab). Students can also be helped to invent their own electronic-based tools and hence learn to "work smart" (e.g., see Bransford, Zech, Schwartz *et al*[7]).
- <u>Opportunities for feedback, reflection and revision</u>: New technologies make it easier to provide the feedback that students need in order to revise and refine their thinking. Computer-based simulations and tutoring environments serve this function[8,9]. Electronic Web-based "challenges" have been used to encourage students to test their current understanding of a topic by attempting to solve a series of problems, posting their answers to a web site and then receiving automatic feedback. These challenges are motivating and increase student learning as well [10]. Teachers' opportunities to provide feedback can be increased with technology. For example, a computer-based tool for providing feedback on student-generated blueprints cut in half the time that teachers needed to help students improve their work [10].
- <u>Communication and community building</u>: Communication technologies are vital in linking students inside and outside the classroom. Online conferences among classmates allow students to discuss academic issues. Conferences can also be asynchronous, so students don't have to interact at the same time. Electronic conversations can create a permanent database that supplements the fleeting oral conversation of an in-class discussion. Web-based conferencing and teaching systems such as Symphony, Allaire Forums, Lotus Notes plus Domino, and Knowledge Forums are all being evaluated by VaNTH.

Web, Distance and Asynchronous Learning

The last year has seen a growth of interest in e-learning as a business opportunity. Merril Lynch published a research document[11] outlining the potential for a $250B market in e-learning at all levels. This current wave of activity in e-learning has created an impetus for standards that provide content developers and delivery system developers a shared view of how learning content will be structured, packaged, and delivered. These standards aim at providing some assurance that the platforms under development can deliver the learning content under development. The new standards, such as the Advanced Distributed Learning (ADL) Initiative's Shareable Courseware Object Reference Model (SCORM)[12] are being developed. As a way of making content more reusable, the standards see content integration (i.e., navigation) described outside of the content itself. Presently, there are no commercially available authoring systems that generate courseware compliant with ADL's SCORM standard. There is a body of work that addresses features of such a system, such as delivery sequencing and the reuse of learning objects. Other features are left unsupported, such as the explicit definition of learning objectives, the association of learning objectives with content elements and domain concepts, and the collection of metadata required by standards such as SCORM.

Research on courseware authoring systems has been conducted for over two decades, with a particularly high level of activity in the mid-90s in the area of intelligent tutoring systems (ITS)[13]. ITS bring together explicit models of expertise (domain knowledge), instructional strategies, and student knowledge with the aim of using the instructional strategies to align the student's knowledge with the expert's knowledge. Significant work remains in constructing courseware authoring tools that incorporate learning science and are tailored to the domain of bioengineering.

Curriculum Issues in BioE Education

A definitive identification of a core curriculum in bioengineering will not emerge soon. However, it should be possible to link plausible curricular goals to bodies of bioengineering knowledge and skills as identified by the taxonomies. The taxonomies are the key to identifying the areas of knowledge from which curricula may be defined. The other element of the curriculum is pedagogical strategy.

A "core curriculum" is a restricted choice of taxonomical segments that are combined with pedagogical strategies to convey the most vital information in a fixed period of time. Two major questions are then produced: what parts of the taxonomies are most vital at a particular time, and which strategies should be employed to teach them? The ERC is organized to pursue the second of these questions with vigor. The first question is more difficult and the answers depend on many factors.

The ABET program outcomes are an excellent way to lay out some of the issues which need to be addressed in bioengineering education. These outcomes represent a broad consensus in the USA on the outcome of an undergraduate engineering program. They need to be tailored for bioengineering.

While ABET suggested outcomes give general guidance, many questions are unanswered for the specific contexts of bioengineering. At the graduate level, other issues arise such as the balance between biology and engineering in such training.

STRATEGIC RESEARCH PLAN FOR THE VANTH ERC

Our goal is to develop the bioengineering educational system for the immediate future. We seek to establish this system within universities, professional societies, industries and pre-college education. We plan it to nourish and guide the evolution of bioengineering education into the indefinite future. VaNTH cannot accomplish all of this in its lifetime or with its resources. It can act as a thorough demonstration of improvements that are possible and can be a test bed for the refinement of ideas, tools and the training methods that will have impact on the attainment of this goal.

Our strategy has been to enlist, organize and support the efforts of people from 5 disciplines: learning scientists, assessment and evaluation specialists, learning technologists including computer scientists, biologists and bioengineers. These teams have been asked to begin at the research level asking basic questions about the relationship of their fields to bioengineering teaching and learning. Then, building on these findings, they have been asked to create effective tools, methods and teaching materials for selected domain areas of bioengineering. This "enabling technology" plane requires strong interaction among the disciplines to bring the power of their knowledge to bear on specific knowledge granules, modules, courses, and curricula. Then, with some experience in hand, the Center will seek to influence the broader educational system through dissemination and organizational involvement with universities, professional societies, industries and pre-college schools. The relations among these thrusts are given in Figure 1.

In the last year we have made several alterations in the strategic plan. We have restricted the bulk of our development to 4 domains of bioengineering – systems physiology, biotechnology, bio-optics and biomechanics. We now have a design effort in learning technology aimed at identifying new technologies based on learning science opportunities. A

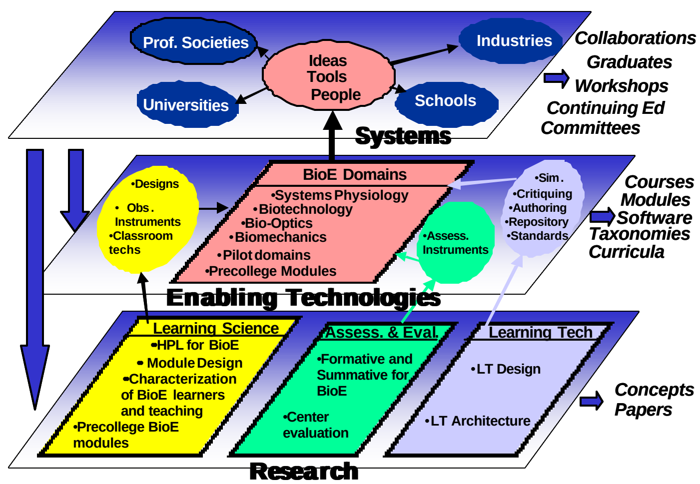

FIGURE 1
DIAGRAM OF THE STRATEGIC PLAN

second activity is aimed at the development of a general systems architecture for the Center. Finally, opportunities have arisen to enlarge our pre-college program. This has led to an initiative to identify collaborating schools and teachers with whom we may partner, and more importantly, to identify how the bioengineering higher education establishment may effectively help these pre-college educators in their responsibilities for science education.

RESULTS

The VaNTH ERC had been operational since mid November 1999. The following accomplishments occurred during these months:

Fundamental Knowledge

- The initial working version of basic guidelines for the construction of taxonomies of bioengineering knowledge and the construction of modules were developed.
- An investigation of the use of modules in a web-based course in How People Learn was performed.
- The first middle school outreach domain was selected (Systems Physiology).
- Learning forums among bioengineering, learning science and learning technology faculty were established for the discussion of vital issues in VaNTH.
- An initial version of design principles for bioengineering instructional modules has been produced and disseminated within VaNTH.
- Baseline studies on the learning characteristics of bioengineering students and the characteristics of the learning environment of the bioengineering classroom have been completed.
- Versions of bioengineering-based materials for pre-college classrooms have been developed and are under evaluation at Chicago public schools.
- Methods and guidelines for formative assessment techniques in bioengineering have been identified and made available to the VaNTH community.
- A strategy for Center evaluation has been formulated.
- Research on using simulations in instruction in bioengineering has been initiated.
- An overall architecture for the digital management of courseware within VaNTH has been developed.
- Taxonomies in 4 Bioengineering domains have been developed and published on the VaNTH website.
- Fifteen modules are under development and are being tested in the domains of Systems Physiology, Biotechnology, Biomechanics and Bio-optics.

Enabling Technology

- A website for both public information and center management and communication was established (www.vanth.org).
- The initial version of a computerized taxonomy/module management system was completed.
- A web-based mini-course on HPL principles has been published on the VaNTH web site.
- Classroom observation instruments and surveys for the bioengineering classroom have been developed and are being tested.
- Computer based Personal Response Systems [14] are being tested as aids to formative assessment in bioengineering classrooms.
- A software framework that allows use of the STAR-Legacy learning cycle [15] in biomechanics has been developed.
- A learning technology support group to aid module developers has been founded.

Education:

- Graduate students and undergraduate students were enlisted and involved in Center research.
- An ERC Research Experience for Undergraduates proposal was written and funded for support of undergraduate students in VaNTH research.
- Investigators analyzed the content of a graduate course in education for appropriate content as an introduction to learning science for bioengineering graduate students. Specific content appropriate for bioengineers was identified and was incorporated into a workshop and a course in this area.
- A course introducing bioengineering graduate students to principles of learning science has been developed and taught.
- Two-day workshops that capsulize the elements of the longer course have been presented to bioengineering teaching assistants and faculty at Vanderbilt, Northwestern and Duke Universities.
- Collaborations with pre-college teachers at Nashville and Chicago have been established.
- Our program on Research Experience for Undergraduates was implemented last summer. A total of 16 students at all VaNTH institutions were supported.
- VaNTH investigators at Northwestern developed a project (funded by NIH) with the Chicago Museum of Science and Industry that will present bioengineering concepts as part of the museum's pre-college educational mission.

SUMMARY

NSF funding as an ERC has allowed the organization of this effort and provided a basis for the assembly of a team of investigators and students to engage in research on bioengineering education. This team has begun to address the significant barriers that exist between our vision of a system for bioengineering education and the current reality. Our efforts should be of direct benefit to bioengineering education, but many features of our plan may also be useful in broader efforts in engineering education.

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