AC 2011-1544: A FIRST COURSE TO EXPOSE DISPARATE STUDENTS TO THE BME FIELD

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A First Course to Expose Disparate Students to the BmE Field

Abstract

This paper describes a sophomore biomedical engineering course that provided a qualitative survey of Biomedical Engineering and introduced ethical considerations to a disparate group of students from various engineering, science and business backgrounds. It was made available as a Science, Technology and Society (STS) elective for engineering and non-engineering students at Clarkson University. As an STS course, it examined the technological bases of innovations in medical technology and analyzed economic and ethical issues surrounding them. No textbook was assigned, nor handouts normally provided. The quality of each student's note-taking was graded. Assessment of the course over the two years that it has been presented is discussed.

Background

In our small but research-intensive university with a strong engineering college, establishing a formal BmE department is not now feasible. However, given its strong commitment to interdisciplinary learning, two complementary Minors in Biomedical Engineering (for engineering students) and in Biomedical Science and Technology (for Arts and Sciences and Business students) were established that share many courses. To help recruit for the minors, an introductory course was needed to grab the students' interest, especially of 1st-semester sophomores but also students at other levels, for BmE. Given the disparate backgrounds and analytical skills of these students, such a course needed to be structured to provide enough engineering principles and examples to be of use to engineering majors, but not so esoteric as to be above the capabilities of other majors.

The course was also designed for our University's Common Experience requirement, for which students must select four courses that cover various Knowledge Areas, including a Science, Technology and Society (STS) area. STS courses must analyze relationships and conflicting cultural values among science, technology, and the health and welfare of humans.

This course examined the technological bases of important innovations in medical technology and analyzes the economic and ethical issues surrounding them. It analyzed advances in biomedical engineering that have impacted human health. The first lectures of a set give an overview of the scientific and engineering principles of a particular advance. The last lectures of a set considered the societal and political responses to that advance, with particular emphasis on ethical issues, and with considerable participatory discussion of selected cases. Advances to aid people with disability were especially covered.

Participants

The sophomore BmE course (BR200) was taught in 2009, and additionally in 2010 when it was also designated as an STS course. There were no prerequisites for this course. Students were from engineering, business and bioscience majors, freshmen to seniors (See Table 1). This table illustrates the great disparity of engineering and science backgrounds that were in this introductory course. Sophomores and Juniors predominated, with more Juniors than Sophomores in 2010. In 2009, 78% of the class were engineering students. In 2010, it was 58%. The majority of engineering students in the class were from Mechanical and Aeronautical Engineering. Seventeen students were fulfilling a requirement for the BmE/ BmS&T minor. Seven Honors students were in the class. One high school student took the course for college credit (and who incidentally had the highest score on her term paper - 3 min slide presentation).

Table 1: Demographics of Students in BR200

A matrix of class attendees by major (rows) and class year (columns) for Fall 2009 and 2010. Also noted are whether they were in the Honors program or had already signed up for the BmE or BS&T minor before taking the class.

2009	Senior	Junior	Sophomore	Freshman	High School	Exchange	Total	Honors?	BmE/BmS&T?
Biology		2	1				3		
Biomolecular Sci		1					1	1	
Business School		2					2		1
Aero E/ Mech E	2	2	6				10	1	3
Chem & BioMol E		3	2	1			6		4
Civil E							0		
Electr E	2		1				3		1
Univ/Engr Studies			2				2		1
	4	10	12	1	0	0	27	2	10

2010	Senior	Junior	Sophomore	Freshman	High School	Exchange	Total	Honors?	BmE/BmS&T?
Biology	2	3	5				10	1	3
Biomolecular Sci			3				3		
Business School	1	1				1	3		
Aero E/ Mech E	2	10	1				13	2	2
Chem & BioMol E		4	2				6	2	1
Civil E	1		2				3		
Electr E	3						3		1
Univ/Engr Studies					1	1	2		
	9	18	13	0	1	2	43	5	7

These demographics show that the majority of the students were not taking the class to fulfill the requirements of the BmE or BS&T minors, since only 10/27 (2009) and 7/43 (2010) had signed up for the minor before taking the class. Thus, an assessment criteria was how many chose these minors while or after taking the class. Six students did so in 2009 and 12 in 2010.

Stated Course Objectives

As noted above, this course was approved as a Science, Technology and Society (STS) elective. This imposed certain requirements for the class. As stated in the University's objectives for an STS course, it must help students be able to: *1) Analyze relationships among science, technology, and the health and welfare of humans and sustainability of the environment; 2) Gain an awareness of information technologies and their impact on society, culture, business, and education; 3) Understand the social and contextual nature of scientific research and technological developments; 4) Analyze conflicting cultural values in scientific and technological research; and 5) Analyze critically the sources of information about science and technology*. As such the following statements were contained in the course syllabus given to each student:

> **Course:** *This is a three-hour survey course whose aim is to give you a brief exposure to the biomedical and rehabilitation engineering field. As such, it is impossible for me to transmit any knowledge to you in detail. I hopefully will present you with a pretty good feel for the field, based on my 35 years of experience in it. To be fair, it also follows that assignments cannot have real depth. But they can be broad, and the can test the developing status of your engineering mind. The overview of necessity will not be comprehensive - rather an in depth look at each topic is left to other topical classes that you will take later in your academic career. In all cases we will try to integrate lectures and clinical findings. It is important that you always understand the clinical implications of what you learn. Finally all that we will talk about will have ethical considerations regarding the use and misuse of technology in medicine. You will need to be in class to be able to understand these subtle ethical dilemmas.*

The educational objectives of this course are to prepare you with an ***oversight*** *of the BmE field and an* ***insight*** *into its applications that will enable you to be productive in you chosen career. These include a knowledge of contemporary topics in medical science and technology, the role of biomedical engineers, and ethical considerations in health care technology.*

Style

The instructor had taught a course similar to BR200 in other universities, and had undertaken a review of the various BmE textbooks that have been published. Good texts certainly abound, whether for medical instrumentation,[1] biomedical engineering,[2] biochemical engineering,[3] or biomaterials engineering.[4] But those focusing on surveying the entire BmE field, especially those edited from a collection of authors, were deemed to be uneven in treatment from topic to topic. None seemed to have the correct focus needed for our disparate and beginning students. None provided an excellent overview of the field while remaining easily understood by students of varying majors. So the question became "*What do we need to impart to our students to give them a very good introduction to the BmE field, to get them enthused about it, and to give them a life-long skill to be able to partially understand what is written or said in the media today about BmE advances.*" The latter includes the many ethical decisions that are made every day. The course's structure evolved from these questions and from the lack of an appropriate textbook.

Without a course textbook, a typical solution might be for the instructor to prepare a slide presentation and an accompanying handout for every session. And this was indeed done for about 1/4th of the class lectures each year, when a considerable amount of background didactic instruction needed to be presented before the ethics and other nuances of a topic could be discussed. Another 1/4th of the lectures consisted of a Socratic Q&A with the class, working it from simple to complex. One-fourth dealt with discussions of case studies, which were often a lead in or follow up to the Q&A sessions. The remainder of the instructional part of the class dealt with current media reports on BmE activities that followed the topic being discussed. Students were required to give a 3-slide, 3-min talk during the last week of the class, accompanied by a 4 or 5 page paper. The presentation and paper were to discuss and analyze one current interaction or research activity at the interface of engineering, medicine and ethics, while allowing students of differing majors to explore areas of BmE of interest to them.

Given that so much of the course depended on instructor-class interactions, where significant unscripted (but theme-driven) information was exchanged, the students were required to take notes in a bound laboratory notebook. A secondary goal of the notebook requirement was to encourage students to learn to take good notes. The quality and content of a student's note-taking for each lecture was graded every two or three weeks based on whether the essence of the lecture (i.e., its 3 to 6 main points) and enough supporting material (like graphs) were captured such that the notebook could serve as a later introductory reference. The students were informed that the final and the midterm would be open-notebook only, with questions would be taken from anything discussed in class or assigned as homework. The students were also required to put any homework assignments into the notebook, and each week also at least one current article from the press or online news that involved technology and medicine or health. When possible, a compilation of the aggregate notes taken by all students was made, and made available to the students after a test was taken.

Content

Every three of four lectures had a main theme, and the class was structured to give the students a conversational knowledge of that theme, before any ethical issues could be discussed. A subtopic once initiated by the students was followed up by a white-board lecture on that topic, always focused within the main theme under discussion.

Many beginning undergraduate students today have a conversational knowledge about certain health care technologies, but most do not know much about the (bio)engineering behind them. As such each was asked in the initial class lecture to write a definition of biomedical engineering, bioengineering, biological engineering and medical engineering. From that, it was clear that many students lacked a precise understanding of biomedical engineering. Hence, one early Socratic class interaction revolved around having the class list various engineering, business and scientific fields, and then drawing out from them how each in turn contributed to medicine and health. In both years, students came up with over 12 engineering disciplines and 8 or so others, and over 100 different ways that these professions contributed. Then the names of various clinical disciplines were drawn out from the students, who then were prompted to name devices, techniques or business advances that aided that discipline or that they had seen or heard about. Again an impressive list was generated. Finally, they were asked to list devices or techniques used at various stages of life, in sickness, in rehabilitation and in a hospital setting (CCU, operating room, bedside). A formal lecture (with slides and handout) on health technology resources allocation (especially with respect to rehabilitation) was given based on Bronzino et al's book,[5] as this information was necessary for many of the ethical issues to be in the class.

As a further prelude to ethical discussions, each student was required as an assignment to successfully complete the web-based CITI *Protection of Human Subjects*[6] course early in the semester. A class session was devoted to this issue, with various technologically based scenarios discussed (e.g., the selection process when dialysis was first available and why justice was not served with that allocation model). This required that the class be given a brief introduction to what dialysis is, how it works, and how artificial dialysis is carried out was discussed from a chemical engineering viewpoint (i.e., a counter-current exchanger).

Brain functioning and the role of technology in the end-of-life debate were introduced early in the semester, especially the Quinlan, Shiavo and Cruzan cases, as were critical care interventions after neural trauma. An overview of the field of neurorehabilitation and its impressive advances in restoring a patient's quality of life also followed in this block. To prepare students for both of these discussions, introductory lectures on the nervous system were presented — enough to give the students some insight into how sensation and movement control are processed, and how trauma can disrupt the process. The world was described as a source of analog signals that are "digitized" by a neuronal analog to digital converter, with the brain's movement commands relayed out to the analog world by a D/A converter at the nerve-muscle junction. Thus the role of the dendrites as summers and axons as regenerating communication channels was covered in engineering terms. A system's schema was presented (sensation→perception→cognition→ volition →action) with illustrations of how prosthetics and orthotics fit within that schema.

This led to the first class ethics discussion of technology resource allocation for three individuals brought to the emergency room with spinal cord injuries (SCI), one a C3 complete, one a T6 complete, and one a C6 incomplete. The instructor gave a few scenarios (e.g., C3=drunk womanizing dad driving, C6= suffering religious wife, T6=addicted 17 y.o. son; and various other combinations). Each group of 4 to 6 students was asked to come up with their own scenario as to the players' histories and to brainstorm what it would cost to rehabilitate each. Given that estimate, they were told that the budget for acute and rehabilitative training and care was extremely limited, and were asked to allocate scare technology resources. They were all aware of responsibility of Justice — the need to treat everyone in the fairly — but had to wrestle with how to apply it in a triage situation. Each group reported out in class. Some really great scenarios were presented (kidnappings, etc.). For homework, each student individually was then assigned to seriously research what technology would be needed, develop cost estimates, and describe how (s)he would allocate the resources, and why. With rare exception, these reports were exceedingly well done. A few students weighed morality as an important consideration (e.g., addicted son gets the least).

A Socratic discussion of critical care technology was interspersed with an explanation of biopotentials (EKG, EMG, EEG), their sources and their clinical value. A lecture on the basis of and use of life-support and/or rehabilitation technology in end-of-life situations followed. This then led to a presentation on three seminal legal cases involving the use of technology in sustaining life (Shiavo, Cruzan, Quinlan). For homework, the students picked one of these cases upon which to elaborate, with a special focus on the role that technology played in the dilemma.

How and why cochlear implants work were covered in a formal lecture (with notes) given by another faculty member at our university with expertise in that area. In the next lecture, he got the class involved in a discussion of the deaf community's view of sign language as their native language, using video and published articles, and the feeling of some in that community that cochlear implants deprived them of that birthright. The students got an appreciation that even though a technology might work well some or most of the time, there are often non-technical factors that limit adoption. Similarly, the body's circulatory system and the role of hemoglobin as the transport agent of oxygen in were presented, followed by a discussion of some religions' prohibition of blood transfusion. Students learned that even though a concept might prove technically feasible, it still could face acceptance problems.

Didactic lectures covering ionizing and non-ionizing imaging, and diagnostic and therapeutic radiation were given, with scientific (physics) explanations for X-rays, PET, CT, MRI, and ultrasound (including Doppler) at an appropriate level for the class. Math models were alluded to where applicable, but not developed any further. Given that background, the class then tackled the recently changed recommendations for the frequency and initial age for mammograms. The concepts of resolution, dose, risk, incidence, prevalence and safety were brought forward. For balance, issues of prostate cancer screening were discussed in the same context. The final ethical issue in this series dealt with reports of X-ray, CT and therapeutic radiation device calibration errors that led to serious harm and even death. For homework, students picked one of these topics (mammogram, prostrate screening, calibration errors) for further research and elaboration, and personal opinion and reflection.

Topics in rehabilitation engineering and assistive technology were covered in a lecture, followed by another lecture showing day-to-day applications of this technology in a caregiver setting. As an assignment, students were given a multi-page survey instrument to be performed in a home setting to gauge the totality of assistive technology needs, and asked to apply this survey over their home break to one of their frail or disabled relatives. They were to write up a report on their recommendations for appropriate technology (and its cost) that would improve the quality of life of the unnamed individual assessed. Futuristic concepts like Brain-Computer-Interfacing (BCI) were presented in another lecture, along with a discussion of possible ethical issues with such technologies. Videos of tremor control in Parkinson's Disease were shown, leading to the introduction of a model of the basal ganglia – cortical control loop of movement as an example of what computational neuroscience can do. A guest lecturer covered limb prosthetics. He assigned an ethical homework question: *Should all veteran amputees (regardless of age and cause of amputation) be given a prosthesis?*

Assessment

Assessment of class outcome was made through exam questions and a term paper requiring synthesis of engineering and ethical issues, a university survey form, by written evaluation of met and unmet expectations, likes and dislikes, and suggestions for improvement, and finally by how many take the minor. Overall, students were enthusiastic about the class, about being required to take good notes in lieu of buying a textbook, and about how ethics were integrated into engineering decisions. For our students, the approach that this course took has served to provide an overview of the biomedical and rehabilitation engineering fields. This paper noted before that 18 additional students signed up for the BmE or BS&T minors while or after taking this class. Since the majority of the class were sophomores or juniors, no post-graduation data are available as of yet as to what careers they ultimately will embark upon. The one high school student in the class will be going to the Albany College of Pharmacy. No data are available regarding whether life-long-learning skills were enhanced, although a number of students continue to occasionally e-mail the instructor links to interesting bioengineering articles that they have read in the popular press or on the web.

For a formal assessment of a course and its instructor, the university uses a 20-question survey. Both the course and the instructor were rated above the school and university norms. Via a separate instrument, the instructor requested unsigned essay answers to the following questions: *"Did the course meet your expectations?" "What did you like about the course?" What did you dislike about the course?" And "What are your suggestions for improvement?"* An administrative secretary compiled the handwritten replies into a database, with answers collated by question. The instructor received the blinded complied set of responses, and grouped together similar comments. One thing to note for this class was that it was offered 8 - 9:15 AM, Tuesday and Thursday. Although about one-fourth of the students complained about the 8 AM class time in Dislikes, absenteeism was always ≤10%, except for 20% for the Tuesday before Thanksgiving.

Approximately one-third of the students each in 2009 and 2010 reacted negatively to the number of class periods that did not use a formal slide presentation. While a few reacted negatively to the fact that there was no textbook for the class, most liked the idea of taking notes. One 2009 participant commented: "*I liked that the course sort of took its own direction and everyday in class was opened ended and we learned about whatever there was to learn that day. It kept the class from being boring and each class did not have the same information over again from the class before it, like some courses are. I liked that we got to use notebooks on the test, especially since once we get a job we will have access to the tools we need to get our work done. The world is* *never "closed notebook" especially now with the internet."* And another: "*The broad range of topics, the amount of information, the fact that we didn't have to by a $200 textbook, the articles we had to fine, the note-taking requirement and all of the papers."* And a third: *"I really enjoyed the in class discussions about the newspaper article topics that were brought in to share. The topics were relevant to today's or future issues within the biomedical field. …"* And finally: *"I liked that we would begin class explaining how a technology worked, studying the science behind it. After we got at least a grasp on how the technology worked we would talk about its real life applications, and any issues that have followed. The class was not intimidating engineering concepts being thrown at us over and over again. It was very well explained and was immediately put in context. Understanding how the science works is important, but understanding how we use it is equally as important and I feel this is overlooked in many other classes."* The inclusion of ethical considerations brought the following comment: "*The thing I liked most about this class was its discussion of medical ethics. I feel that this information was extremely valuable to all those studying biomedical and rehabilitation engineering. I also liked how patients' case studies were examined and was very useful to lean medical terminology used in the medical profession."* These feelings were echoed in the 2010 written comments.

Of the 14 respondents in 2009 who addressed the "meet expectations?" question, 11/14 answered in the affirmative. Two others felt that there was not enough engineering information presented, and one felt that there was too much of an EE slant. Of the 27 respondents in 2010, 23 also said "*Yes,"* and 10 added strong endorsements. Three others were unhappy that one or more specific topic in the syllabus was not covered (one specifically mentioned human genetics) or again had an EE slant. One last respondent said; *"The class was not what I expected, but that's a good thing. I went into this class thinking that I was getting way over my head, and was doomed to fail. Now I find myself thinking of it as one of my favorite classes."*

The instructor had some concerns about how the notebook requirement would be accepted. It turned out to be an oft-mentioned "like" about the course: " *I liked the notebook system; it really strengthened the learning environment and gave a good reason to come to class every day. I also enjoyed the 8:00 AM time slot because it got me up and around early on Tuesdays and Thursdays."* And another: *"It was interesting and I liked when we did activities that got the class involved in the lecture. I liked how the notebooks were used as the textbook; I also liked how it was very easy to pay attention in this class even though it was very early. The homework assignments were interesting."* A "dislike" of 4 students in 2009 was that the instructor did not write clearly enough on the white board during the myriad of extemporaneous discussions that occurred in the class. The instructor made a conscious effort to correct this deficiency in 2010, but still 6/43 students then had difficulties in that regard. The ability to expand didactically on topics raised contemporaneously during class is an essential part of this course, and the use of the white board is the most effective way to do it. The instructor remains reminded of the need to write large and legibly in class.

The course can also be assessed relative to the University's written requirements for a STS course. When judged against them, this course did help each student

1. *Analyze* [well] *relationships among… technology and the health and welfare of humans;*
2. *Gain a*n *awareness of* [medical] *information technologies and their impact on society…* [by discussing risks and benefits of electronic medical records and personal health records]*;*

3) *Understand the social and contextual nature of … technological developments* [through the ethical discussions held throughout the semester]*;*
4) *Analyze conflicting cultural values in … technological research* [via a discussion of current Human Research Protection Policies and past misuses, and end-of-life scenarios]*; and*
5) *Analyze critically the sources of information about science and technology* [through each student's weekly clipping of articles of BmE interest, and their discussion in class].

The final "assessment" was how well every student integrated bioengineering concepts and ethical considerations into the final paper that they wrote for the class. It could be written on any topic, but the elements were to include a BmE advance or use, a medical or health application, and ethical considerations if appropriate. These three elements were equally weighed in grading. A great majority of both classes [39/43 in 2010, 27/27 in 2009] were able to synthesize together these three elements in a well-written, cohesive discussion. There is hope for engineers (and others) as writers!

Discussion

A major premise behind the offering of this course as an STS elective was that it might be the first and possibly the last formal academic exposure of a disparate group of students to the biomedical engineering field. So, to make for a good introduction, the course had to cover a representative range of topics, energize its students, and promote in them a life-long appreciation of the field. Introducing bio-ethical considerations helped internalize the course content for the students, as well as helped to satisfy the objectives for an STS course. An important distinction is that the course was not *per se* a bioethics course.

The broad content of the course required that the instructor synthesize inputs from a variety of sources that included bioengineering textbooks,[1-4] textbooks and reference works on bioethics in general[7-9] and on ethics and emerging technologies,[5,7,10-13] books and presentations on rehabilitation attitudes and ethics,[14-16] and finally reports by others on bioengineering ethics and STS education.[17-19] This material was further augmented by discussions of articles gleaned from the press (e.g., NY Times weekly Science section) and internet by the students and the instructor.

The assessment by the students indicated that the mix of didactic, Socratic, current events and case-based learning techniques was an appropriate way to introduce the biomedical engineering field to beginning engineering and non-engineering students. The students were energized, participated in class discussions, and did well on assignments and presentations that required them to combine BmE and ethical considerations.

Conclusion

The purpose of this conference presentation has been to describe a sophomore biomedical engineering course that provided a qualitative survey of BmE and introduced ethical considerations to a disparate group of students from various engineering, science and business backgrounds. The teaching approach taken led to nearly full attendance for almost every 8 AM lecture. The class served as a fitting introduction to BmE to beginning engineering and other students, and hopefully will encouraged students to continue with BmE classes and potentially into BmE careers.

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