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Teaching Science, Technology, and Society to Engineering Students: A Sixteen Year Journey

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Abstract The course Science, Technology, and Society is taken by about 500 engineering students each year at Bilkent University, Ankara. Aiming to complement the highly technical engineering programs, it deals with the ethical, social, cultural, political, economic, legal, environment and sustainability, health and safety, reliability dimensions of science, technology, and engineering in a multidisciplinary fashion. The teaching philosophy and experiences of the instructor are reviewed. Community research projects have been an important feature of the course. Analysis of teaching style based on a multi-dimensional model is given. Results of outcome measurements performed for ABET assessment are provided. Challenges and solutions related to teaching a large class are discussed.

Keywords Science, technology, and society education · STS education · Engineering ethics education · Teaching large classes · ABET · Accreditation · Community research

Introduction and History

The purpose of this paper is to share my experience teaching the course *Science, Technology, and Society* at Bilkent University, Ankara (Ozaktas 2006, 2008), with the hope that it may be useful for those teaching or planning related courses. The rigor of engineering education leaves little room for reflecting on the nature of technology and science and their interactions with society. This course is designed to initiate students into critical thinking and self education beyond the technical confines of their academic discipline, with the belief that this will make them not

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only better professionals but also better citizens. The course is compulsory for engineering majors and is taught in English. It meets for 28 h and is worth 2 credits out of about 135 required to complete the four-year BS degree program. It is probably the first course in Turkey to deal broadly with the ethical, social, cultural, political, economic, legal, environment and sustainability, health and safety, reliability dimensions of science, technology, and engineering.

During the early nineties, gaining ABET (Accreditation Board for Engineering and Technology) accreditation became a goal for elite universities in Turkey. Until that time the need for incorporating ethics or social dimensions courses in engineering programs had not been felt by most institutions. ABET clearly specified this as an essential component, but there was neither any institutional experience nor examples to follow in Turkey. I took this opportunity to propose this course in 1995 and since then it has been the key course in meeting ABET requirements on ethics and social dimensions.

Originally the course was offered to about 160 Computer-Electrical-Industrial Engineering students. However with the threefold increase in admissions, the course now has nearly 500 students, and with the new Mechanical Engineering Department will exceed this number. The large class size will be discussed in section "Teaching Large Classes". But first I will give an overview of the scope, objectives, and philosophy of the course in the next section. In the section that follows, I will discuss community research projects. Section "Analysis of Teaching Style Based on the Felder–Silverman Model" provides an analysis of the course based on a learning styles model. ABET outcomes relevant to the course and their assessment are discussed in section "Outcome Measurements and ABET Accreditation".

Scope, Objectives, and Philosophy

There exists considerable discussion of the Science, Technology, and Society (STS) approach in elementary and secondary education (Yager 1990; Kumar and Chubin 2000; McGinnis and Simmons 1999; Yalvac et al. 2007; Lee and Erdogan 2007; Kaya et al. 2009; Akcay and Yager 2010). Proponents have argued that this approach addresses several difficulties of traditional science education, stating that it is more holistic, student oriented, and accessible by virtue of its embedding scientific facts and principles in a social and technological context meaningful to students (Yager 1990).

In elementary and secondary education, the essence of this approach is the integration with the teaching of science. The purpose is not only to teach and encourage thinking about science, technology, and society interactions, but to improve the teaching of science itself and make it more meaningful. In a science or engineering degree program, I am not aware of evidence that such integration would contribute significantly to the teaching of science and engineering subjects. Integration of STS and ethics education throughout the degree program is nevertheless desirable and some strategies have been proposed (Davis 2006; Cruz and Frey 2003). Otherwise it becomes relegated to the status of an "appendix" of the program, rather than an integral part of it. Students will likely perceive its relevance as low and also possibly be less able to apply what they have learned. The difficulty is that most engineering faculty members who teach traditional technical courses do not have the background or inclination to undertake meaningful integration. Furthermore, this is not a very easy task to begin with since most engineering courses are traditionally taught in a fashion which is highly divorced from real engineering practice. (Senior capstone design projects are an exception and offer the best opportunity in this respect.) Without major changes in engineering education, it is likely that most institutions will find integration difficult in practice. In this context, it would be interesting to compare and contrast engineering education to education in other professions such as architecture, accountancy, law, medicine etc. Furthermore, it would be interesting to investigate whether this issue has more to do with pedagogy or with the material that is taught.

The present syllabus has a current issues focus and emphasizes subjects students would be familiar from the media with the hope that they will be able to more easily relate to such topics: Ethics and technology and ethics codes. Political positions and science and technology issues. History of technology. Conventional and alternative energy. Ecology and environmental issues. Population. Health and technology. Technology and development. Intellectual property, copyrights, patents, and trade secrets. Philosophical aspects of artificial intelligence. Technological disasters. Responsibilities of scientists and engineers. Technology decisions and the democratic process.

It has been argued that such courses should not be limited solely to discussing current controversies and that there are many lessons to be learned from studying the interactions of technology and society throughout history, aided with a social and cultural studies approach (Lee 2010). For instance, we discuss how the use of certain technologies around the time of the Renaissance has resulted in changes that in turn supported the growth of secularism in Europe. However, presently the social and cultural studies orientation of the course is less pronounced than it was in its early years (Ozaktas 1996).

Additional topics are covered through guest seminars and video showings. An advantage of the large class size is that it becomes possible to attract high profile speakers. Our speakers have included ministers and members of parliament in addition to high-ranking officials, civil-society leaders, entrepreneurs, and academics. Care must be exercised in choosing speakers to ensure students are exposed to different points of view.

Many engineering departments who seek to meet educational or accreditational objectives choose to implement "engineering ethics" type of courses. These courses often contain an overview of ethical theories followed by case studies. While this is a legitimate and worthy approach in itself, I have argued that this content is insufficient if there is room for only one such course in the curriculum. Therefore, I have chosen to follow a "Science, Technology, and Society" studies approach, which can deal with the diverse manifestations of the interaction of science, technology and society in a more multidisciplinary fashion. For instance, we spend more than a week studying technological disasters. It has been argued that this topic provides rich material for study and has many advantages (Luegenbiehl 2007), but it has also been argued that disasters are unsuitable as ethics cases because of the difficulty in separating the ethical aspects from the social, political, and economic aspects (Davis 2007). This is precisely the rationale for choosing a multidisciplinary STS studies approach.

I have also found that students are more receptive to this approach, since it is easier to relate to current social–political–economic issues and since this approach is less abstract than a philosophical approach. Value judgments and ethical issues permeate virtually all topics that we cover, and my experience is that students are more inclined to confront ethical issues in this manner, when compared to some traditional case study approaches. A particular weakness found in certain earlier approaches is the downplaying of social, cultural, and organizational context. Such approaches tend to diminish the importance of systemic injustices and the possibility of collective efforts to solve them, and reduce ethical dilemmas to private choice of the individual, who must choose between right and wrong, or who must weigh conflicting values. Cases such as "Should I blow the whistle given that I may lose my income and not be able to support my family?" or "Is it acceptable to bribe officials in foreign countries if it is widespread there?" can sometimes tend to be a bit lifeless, and also incomplete when considered in isolation. This point is also related to the distinction between "microethics" and "macroethics" (Herkert 2001, 2005; Kline 2010). Microethics deals with relations among individual engineers, managers, and employers. Macroethics deals with collective social responsibility and societal decisions. It has been unfavorably observed that in most engineering programs individualistic approaches dominate and macroethics receives considerably less attention (see Colby and Sullivan 2008; Bucciarelli 2008; Conlon and Zandvoort 2011, which also include further references, and also Winner 1980). Comparison of North American and European approaches to engineering ethics may be found in van de Poel et al. (2001).

Community Research Projects

Various novel project concepts have been developed throughout the history of the course, including web-based projects and the incorporation of the concept of *Community Research*. In contrast to "High Technology" and "Big Science" (research heavily funded by governments and corporations and practiced by professional scientists), Community Research involves communities in the identification of problems affecting them (such as public health and social issues) and encourages their participation in applying the results to directly improve their lives (Loka Institute 2011). It is also related to *Grassroots Science* (Hansen 2005), *Science Shops* (Living Knowledge 2011), and *Humanitarian Engineering* (Humanitarian Engineering 2011). The 160 students taking the course at the time were required to propose and undertake a project of this nature in groups of 8–12 students. They were definitely motivated by the real-life nature of the projects and the concrete aims. The educational value was immense. In recent years, community-based learning, also called service learning, has become widely recognized and used in many disciplines, with a number of studies showing its benefits (Colby and

Sullivan 2008; Stanton et al. 1999; Eyler and Giles Jr. 1999; Pascarella and Terenzini 2005).

Since this is essentially a social issues course, I see personal involvement and engagement at an emotional and social level as important keys to deeper learning. Here deeper learning refers not only to a greater level of penetration, assimilation, and connectedness, but also to learning with a subjective component, which goes beyond the objective learning of facts, concepts, ideas, and skills. Being creative, making choices, taking individual and collaborative action, and reflecting upon the local and global consequences of ones actions are important components of this process whose learning benefits have been recognized (IB Organization 2011; Brugge and Kole 2003). Community research projects have the potential to combine these components of learning with the application of technical knowhow to solve real-life problems, and can provide an excellent opportunity for deep learning.

Analysis of Teaching Style Based on the Felder–Silverman Model

In a highly cited article Felder and Silverman have set forth five dimensions of learning and teaching styles (Felder and Silverman 1988). Each dimension is characterized by its extreme points which represent opposing styles, and the necessity of accommodating both styles of students in all dimensions is emphasized. Here I discuss our course with respect to this scheme.

Perception and Content

Learning styles: *sensing* (external: sights, sounds, physical sensations) versus *intuitive* (internal: possibilities, insights, hunches). Corresponding teaching styles: *concrete* (factual) versus *abstract* (conceptual, theoretical).

In earlier years I mostly used abstract-conceptual-theoretical texts, soon discovering that students were not very receptive to this material (for instance Ozaktas 1996; McGinn 1991). This is consistent with research showing that the majority of engineering students are sensors (Felder and Silverman 1988). The more recent current issues approach (Ozaktas 2011), based on the texts Hjorth et al. (2003), Evan and Manion (2002), Easton (2008), is substantially more concrete and factual. Some abstract content, such as an introduction to the philosophy of science has been retained, in order to expose students to ideas and ways of thinking in areas in which they show weakness.

Input and Presentation

Learning styles: *visual* (pictures, diagrams, graphs, demonstrations) versus *verbal* (spoken and written words, sounds). Corresponding teaching styles: *visual* (pictures, diagrams, films, demonstrations) versus *verbal* (lectures, readings, discussions).

It has been found that most people of college age and older are visual (Felder and Silverman 1988). Our major textbook (Hjorth et al. 2003) contains a good deal of pictures, diagrams, and graphs to supplement the text. Additionally, video showings are an integral part of the class and I encourage use of illustrations and video material heavily by guest speakers. Nevertheless there remains room for improvement in increasing the visual component in ordinary lectures, which are dominantly verbal. On the other hand, while I believe in increasing visual input to aid student learning, I also believe that reducing reading material will reinforce certain negative trends among students (such as lack of concentration for and inability to extract the essence of long texts, partly caused by the fragmented media environment) (Carr 2010). Thus the expectation that they read longer texts must be maintained. Although class size does not permit in our case, I also believe that active verbal discussion and debating remains of paramount importance. The need to balance the students learning styles has been similarly argued in Kolmos and Holgaard (2008).

Organization

Learning styles: *inductive* (facts-observations given, underlying principles inferred) versus *deductive* (principles given, consequences-applications deduced). Corresponding teaching styles: *inductive* (phenomena leading to principles) versus *deductive* (principles leading to phenomena).

Felder and Silverman argue that induction is the natural human learning style and therefore they are in favor of the inductive teaching style. A similar belief seems to underlie the recent popularity of methods referred to by names such as active learning, discovery learning, inquiry-based learning, or la main à la pâte in diverse levels of education (Bonwell and Eison 1991; La main à la pâte 2011). The present design of the course hardly contains any deductive approaches, indeed it covers relatively little in the name of theory and general principles. Therefore, the criticism may be raised that an inductive approach leading to theories and principles is also not sufficiently emphasized. The reason for including limited theoretical material is primarily our engineering students' lack of receptiveness to this type of material and my experience that attempts at forcing it become counterproductive. Students may to some extent be spontaneously generalizing from the material they are exposed to and arriving at some sense of the underlying principles on their own, but since this is not very reliable, it would be worthwhile to try to devise ways to structure and guide this process.

Processing and Student Participation

Learning styles: *active* (through engagement in physical activity or discussion) versus *reflective* (through introspection). Corresponding teaching styles: *active* (students talk, move, reflect) versus *passive* (students watch and listen).

It has been noted that there are indications that engineers are more likely to be active than reflective learners (Felder and Silverman 1988). Discussion and debate are very appropriate modes of activity for this course, since it covers many controversial issues. With a class size below 20–30 I would spend most of the class time actively engaging students in discussion. With 500 students the possibilities are more limited, but still do exist. Mass voting on contentious issues is one of the techniques I frequently employ. Sometimes I take 10–20 two-choice or three-choice votes through a 2 h session, allowing the students to better define their positions. I also ask representative students to voice reasons for their votes. I also encourage students to give collective feedback through cheering, shouting, or bodily movements, much as in a spectator sporting event or rock concert.

Understanding and Perspective

Learning styles: *sequential* (in continual steps) versus *global* (in large jumps, holistically). Corresponding teaching styles: *sequential* (step-by-step progression: the trees) versus *global* (context and relevance: the forest).

In contrast to most university teaching which is sequential in nature, this course does not exhibit a strong imbalance in favor of sequential or global styles. Since we focus on macro as well as micro problems, students have the opportunity to see both the forest and the trees.

Outcome Measurements and ABET Accreditation

Although based in the United States, ABET also conducts non-US accreditation using the same accreditation criteria and the same policies and procedures as in the US. In the past, ABET evaluated programs outside the US to determine if they were "substantially equivalent" to ABET-accredited programs. However, substantial equivalency was not considered accreditation. ABET is no longer conducting substantial equivalency evaluations (Accreditation Board for Engineering and Technology 2011). The Association for Evaluation and Accreditation of Engineering Programs (MÜDEK) fulfills a similar purpose in Turkey. MÜDEK is recognized by the Higher Education Council of Turkey. It is a full member of ENAEE (European Network for Accreditation of Engineering Education) and is authorized by ENAEE to award the EUR-ACE Label (Association for Evaluation and Accreditation of Engineering 2011). While some institutions are still undergoing ABET accreditation, with MÜDEK having joined the Washington Accord (Washington Accord 2011), it is expected that MÜDEK accreditation will replace ABET accreditation in Turkey.

Of the eleven ABET student outcomes, outcomes (f) and (h) are relevant to our course. The extent to which these are achieved by our students is measured by a set of criteria which each department specifies; those of the electrical engineering department are used here as an example:

- Outcome (f) An understanding of professional and ethical responsibility.
  - (f2) Should demonstrate understanding of the impact of technology on society.
  - (f3) Should be able to identify and clarify ethical issues and conflicts and relate courses of action to values.
  - (f4) Should exhibit basic familiarity with applicable ethical codes.

- Outcome (h) The broad education necessary to understand the impact of engineering solutions in a global, economic, environmental, and societal context.
  - (h1) Demonstrate basic knowledge and understanding of ethics, history of technology, politics of technological choice, environmental issues, energy issues, population issues, and health and safety issues.
  - (h2) Demonstrate basic understanding of the positive and negative impacts of engineering and technology, and relate these impacts to values.

These are measured through designated exam questions in the course, while additional criteria f1, f5, h3, h4 are measured through other means. Student scores for each criterion are mapped to ranges designated as “Does not meet the criterion,” “Meets but does not exceed the criterion,” and so forth. Table 1 shows the percentage of those who meet or exceed each criterion. It is not likely that true student learning varied significantly over three years, so that outlying data values are likely a result of the difficulty of calibrating the score ranges with respect to variations in the difficulty of the questions. Therefore I concentrate on averages over the three years. Roughly speaking, it may be concluded that about three quarters of the students have met the criteria and about a quarter have not. This falls short of our goal of 85–90 success rate (such a high percentage goal was chosen since the percentages refer to the number of students meeting or exceeding minimal requirements; ideally almost all students should meet minimal requirements). An important note in this regard is that until very recently a very lenient grading policy was employed. The fact that the course was considered “easy” among students, with extremely low fail rates, probably reduced the incentive for students to prepare more rigorously for examinations. The ABET process is now forcing higher standards in grading. When the adjustment process is complete we expect to achieve our target rate.

Teaching Large Classes

When we had 160 students, there was a common lecture hour and three discussion sessions with about 50 students in each. Later, the class population rose to around 500, without an increase in the teaching resources allocated to the course. (Each faculty member teaches four section equivalents per year, with typically 50 students per section. Teaching of this course was originally considered two section equivalents, and remains so.)

Table 1 Percentages of students meeting or exceeding the criteria

	2008	2009	2010	Average
f2	77	87	59	74
f3	78	75	72	75
f4	96	79	87	87
h1	80	50	74	68
h2	92	49	72	71

The increase in class population necessitated the elimination of term papers/projects and discussion sessions and limited instructor-student exposure to lecturing in a large hall. This forced me to study techniques of teaching very large classes (Stanley and Porter 2002; Heppner 2007). The many books on teaching large classes is evidence of a trend to increase class sizes, which seems primarily driven by the need to cut costs.

Proponents of large classes argue that quality can be improved at the same time as costs are reduced (Gibbs and Jenkins 1992). This may indeed be possible in certain cases, but for this course I believe some of the benefits of small sections are lost without compensation. The social, personal, and even moral nature of the subject matter requires personal involvement for true learning and growth to take place. Students must be confronted with others opinions and forced to formulate, articulate, and defend their positions in live social encounters. Actively nurturing such involvement through appropriate challenges is usually beyond the ability of most teaching assistants.

The fact that generations of faculty members have went through their own education without taking such courses contributes to them being considered of secondary importance with respect to technical courses. They are seen necessary to fulfill accreditation or other requirements, but few genuinely believe in their essential importance. This partly explains the tendency to meet the requirements with minimal cost. (The arguments of Hughes (2000) may also be relevant.)

Confronted with a large number of students, I have experimented with a number of techniques to increase participation and maintain student attention. These include assigning debate topics to groups of students who are expected to compose arguments for or against a certain position on a controversial topic. Texts from the *Taking Sides* series such as Easton (2008) were found useful for this purpose. Selected opposing groups debate on stage in front of the whole class, while the remaining students must prepare a critical outline of the discussion. During the two hour lectures, five minute reflection and recollection breaks are given every half hour or so with music in the background. The large audience also requires considerable stage performance. Hiding behind a lectern is the worst thing one can do. What seems to work better is constantly moving around the stage and using large visible gestures much like a pop or rock soloist. I frequently employ techniques of mass voting and collective opinion forming to involve the class as much as possible. As noted before, I firmly believe that in a social issues course, involvement at an emotional and personal level is essential for learning. Therefore these techniques become especially effective when it is possible to mobilize strong opinion or sentiments among the students. When they are cheering or shouting I feel I have accomplished one of the key conditions of true learning.

Future Prospects and Challenges

Several of the difficulties facing effective engineering ethics education (Zandvoort et al. 2000; Newberry 2004; Zandvoort 2008) are also relevant to STS education. I have already underlined the importance of mobilizing the strong feelings and self-identification of students as they explore who they are, what they want to be, and how they wish to relate to local, regional, and global society. Much greater opportunity for this exists with small classes, where the instructor can personally model social responsibility, interact with students at a personal level, and there is the opportunity for the instructor and students to challenge and provoke each other, which facilitates the process of taking sides and self-reflection. Section sizes below 25 students would be ideal, but are currently unrealistic. This would increase cost greatly, and it would not be easy to find qualified instructors. In this context it is worth noting that worldwide such courses have been taught by instructors from both technical and social sciences and humanities disciplines. However, instructors from technical disciplines are only rarely qualified and interested, while those from the social sciences and humanities may not recognize the need, or be willing, to make the necessary adjustments in teaching science and engineering students. The best approach may be team teaching by instructors from both sides (Zandvoort et al. 2008).

My informal observation is that the degree to which students do well and benefit from this course is to a great extent determined by their attitude towards it. While some students, especially those with an interest in social and political issues, find this course very interesting and important, some are either not interested, or because of their highly technical orientation find it difficult to master.

Thus major challenges for the future are to find better ways of increasing involvement and engagement despite the large class size, and to better reach students with lower levels of enthusiasm. One possibility is the greater use of educational technology (Bird and Sieber 2005; Loui 2005). The use of discussion forums, social networks, and classroom response systems ("clickers") may hold some promise but will require careful design and evaluation.

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