Session 3661

Women, Food, and CFCs: A Technological Literacy Course Based On the History of Refrigeration

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Abstract

This paper describes "Engineering, the Human Enterprise," a technological literacy course which was first offered at the University of Massachusetts Amherst in the fall of 1997. The course treats the common household technology of refrigeration from historical, technical, and environmental points of view. Following a review of domestic American housekeeping and the problems associated with food preservation, the history of the natural ice industry in the U. S. is traced from its beginnings in the 1820s through its demise after the advent of mechanical refrigeration. We then introduce enough qualitative thermodynamics concepts to enable students to understand the basic vapor-compression refrigeration cycle, aided by instructional software developed specifically for the course. In the last part of the course, students learn how the chlorofluorocarbon refrigerants hailed as "wonder chemicals" in the 1930s turned into a global environmental problem in the 1970s, and write term papers in which they explore a particular concept or issue of their choice in greater depth.

Student response to the course has been positive. The same basic historical problem-solution-problem format can be applied to other technologies, including the automobile, electronic communications, and the computer. A discussion of curricular and philosophical issues relating to technological literacy courses such as this one concludes the paper.

I. Introduction

Professional schools such as law, medicine, and engineering have not traditionally offered courses designed for students who do not plan to enter the school's profession. There are at least two reasons to offer such courses, however. First, the motivation for so-called "service courses" is utilitarian. For example, engineering students need foundations in mathematics and physics which are best taught by members of the departments of mathematics and physics, which therefore offer service courses to students in other departments. Since the study of engineering at the undergraduate level has not traditionally provided a foundation for the practice of any profession other than engineering, few non-engineering students take engineering courses for purely utilitarian reasons.

The second reason for such courses is cultural. Nearly all institutions of higher learning have "general education" or "core" requirements which constitute the school's notion of what an educated person should know. From relatively rigid, prescriptive structures in the early 20th century, the core requirements of most universities have evolved into electives from several broad categories with names such as "social world" and "quantitative reasoning." [1] An argument can be made for the idea that in a world increasingly shaped by technology, a college education should include the opportunity to learn how the fundamentals of science are applied in technology to satisfy human needs and desires–in other words, to learn about engineering in its wider social context. Technological literacy courses address the cultural reason for teaching technology and engineering to non-engineering students. As representatives of the profession of engineering, engineering professors are among those best qualified to teach such courses.

A technological literacy course should satisfy several criteria. First, it should deal with a technology that is familiar to most students, ideally something most of them use in their daily lives. Second, if the course is to have the widest possible appeal, students should be able to understand its basic technical concepts qualitatively, that is, without the use of advanced mathematics. Third, there should be sufficient reference material available on the history of the technology involved as well as on relevant current issues.

This paper describes a course entitled "Engineering, The Human Enterprise" which was developed to satisfy these criteria. The course is presently structured around the technology of the household refrigerator, and uses this technology as a base from which to explore related issues in fields as diverse as social history, biology, physics, marketing, and environmental science. We present the course as a work in progress, since at the time of this writing it has been offered only three times to a small number of students. Nevertheless, we feel that this presentation of the course's structure and special features, and our experiences in developing it, will be helpful to those who create similar courses in the future.

II. Course Structure

The course begins with a historical introduction, which can likened to the top slice of bread in a sandwich. About a third of the way through the course, the students encounter the technical "meat" in which they learn in a qualitative way how the vapor-compression cycle of a household refrigerator works. In the last third of the course, they study the story of chlorofluorocarbon compounds, which were first hailed as the perfect refrigerant in the 1930s and then condemned as harmful to the ozone layer in the 1970s.

A. *Historical Section: Homemaking and Natural Ice*

Every engineered product or service should satisfy a human need or desire. In order to make sense of the growth of domestic refrigeration, we set the stage with a brief study of food preparation in the typical 19th-century American household. We emphasize the inconvenience of having to buy fresh foods every day, the problems involved with the preservation of perishables such as meat and milk, and show how most of the burden of dealing with these difficulties fell upon the women of the household plus the occasional servant. We rely for this information upon "domestic economy" books of the period, notably *The American Woman's Home* by Catharine E. Beecher and her more famous sister Harriet Beecher Stowe.[2] A more recent treatment of these issues by a well-known historian of technology is Ruth S. Cowan's *More Work for Mother*.[3]

After a lecture on the biology of food spoilage, student teams perform a biology experiment in which they allow common household food items such as bread, meat, fish, and fruit to sit at room temperature for 7 to 14 days. This brings home the importance of the refrigeration chain for food products that some students have never studied in the decayed state. Convinced of the need for food refrigeration, they next learn about the growth of the American trade in natural ice, which began in the 1820s when New England shippers found a ready market in the Caribbean for winter-grown Northeastern ice. *Refrigeration in America* by historian Oscar E. Anderson is the single best source for historical information on this field up to the 1940s.[4] At the end of this first section of the course, students know that low temperatures retard food spoilage, and they are aware of the significant effects that the natural ice trade had upon food production, distribution, and consumption by the 1880s. But they also know that the natural ice business was subject to crop failures caused by warm winters, and how the limitations of existing transportation networks prevented the natural ice industry from serving many areas which could have used its product.

B. *Technical Section: How a Refrigerator Works*

With their awareness of the problems and limitations of natural ice, the students are ready to learn how the science of thermodynamics and the technology of the steam engine led to the development of mechanical refrigeration in the late 1800s. This section of the course has a single clearly defined goal: to teach the students a qualitative explanation of how a vapor-compression household refrigerator works. We spend about a week on the conservation of energy and interchangeability of forms of energy, drawn from examples chosen by the students themselves. At this point the students are ready to trace energy flows through the four basic parts of a refrigerator: the evaporator, the compressor, the condenser, and the capillary tube or expansion valve (which for reasons of symmetry we call the "expander"). The special means we use to teach this set of concepts are described below in Section III.

C. *Recent Events: CFCs and the Ozone Layer*

With their newly gained understanding of mechanical refrigeration, the students can now appreciate why refrigeration engineers greeted the first chlorofluorocarbon refrigerants with delight when these chemicals were introduced around 1930. In contrast to older toxic refrigerants such as ammonia, sulfur dioxide, or methyl chloride, CFCs appeared to be nearly ideal: nontoxic, non-corrosive, and not too expensive. By studying CFCs in this historical context, the students can see how the passage of time must be considered in making judgments about technical issues which have broad social and political implications. They learn how large-scale industrial research and development and mass marketing methods created a tremendous market for mechanical refrigerators, which also led to greatly increased production of CFCs. Finally, they find out how CFCs harm the ozone layer and what steps have been taken to head off the problem. By this point, the students are prepared to choose a topic for a term paper, which is turned in shortly before the end of the course.

III. Special Features

A. *Guest Lecturers*

The existing rules for approval of "general education" courses at the University of Massachusetts Amherst require that courses under the "interdisciplinary" designation have substantial content from more than one discipline. (The reasons why this course was designed for the interdisciplinary designation are given below in Section IV.) One result of meeting this requirement was that the course content had elements from disciplines such as biology, history, and environmental engineering which the instructor felt less than completely competent to deal with. This problem was solved through the use of guest lecturers from the appropriate departments who give one talk each in their area of expertise.

In general, collaborative or team teaching across departmental lines is difficult because it confuses the administrative allocation of teaching resources, which are assumed to stay within departmental bounds. In plain language, teaching activities outside one's own department do not "count" to one's credit in the department's assessment of teaching loads. However, every professor we approached in another department was willing to volunteer the more limited commitment of a single lecture on a topic familiar to them. The course as currently offered features guest lectures from faculty in consumer studies, food engineering, the history of technology, and environmental engineering, and others could be added as well.

B. *Refrigeration Cycle Teaching Aids*

In its present form, the course has no prerequisites. This throws it open to freshmen as well as seniors, and means that students can be assumed to have only the most basic mathematical abilities. The challenge of teaching a meaningful version of the vapor-compression refrigeration cycle to students who are innocent of both thermodynamics and calculus was met with a variety of techniques.

1. *Bicycle Refrigerator*

During the first offering of the course in the fall semester of 1997, we constructed a bicycle-powered refrigeration demonstration with the help of mechanical engineering undergraduate students. To emphasize the expansion and compression of the refrigerant (which was environmentally-friendly type R-134a), we stored it at atmospheric pressure in an inflatable beach ball and compressed it into a glass-walled receiver with a bicycle-powered single-cylinder compressor. (The glass wall allows the students to see that the compressed refrigerant is indeed a liquid.) Fig. 1 illustrates this apparatus being operated by one of its constructors, Miss Vicky Ryan. Unfortunately, this design made it impossible to evacuate air from the system before operation. Consequently, the condenser part of the cycle never worked properly and we had to supplement the compressed refrigerant vapor from the beach ball with a direct injection of liquid refrigerant from a storage container into the receiver. This did not prevent us from demonstrating the most dramatic part of the cycle, however. On cue, a volunteer from the class opened the expansion valve to release compressed liquid refrigerant from the receiver directly onto a small quantity of water in an expansion chamber. The resulting *whoosh*, clouds of condensed water vapor, and chunks of ice convinced the students by direct experience that expanding refrigerant gets cold enough to freeze water. Although we made videotapes of the bicycle-refrigerator demonstration for possible future use, we have since found that the simpler demonstration of releasing compressed liquid refrigerant directly from a storage container into a jar of water is just as effective in conveying the central idea, and much less trouble. [5]

Fig. 1. Vicky Ryan, graduate of the University of Massachusetts Amherst Department of Mechanical and Industrial Engineering, demonstrates a bicycle-powered refrigerator for undergraduate students.

2. *Refrigerator Tutor*

While educational software is available to simulate various gas laws in physics, we could find nothing on the market that covers the vapor-compression refrigeration cycle at the level of detail and technological sophistication we desired. Accordingly, over a two-year period we developed a custom multimedia instructional package called the *Refrigerator Tutor*. In designing the tutor in collaboration with Tom Murray of the University of Massachusetts Amherst Department of Computer Science's Center for Knowledge Communication, we created a fantasy journey through a refrigerator. An artist devised a penguin character to take the journey, and portrayed a series of scenes accompanied by narration and suitable sound effects. The Tutor's title screen is shown in Fig. 2. After the user follows the penguin through a complete vapor-compression cycle, the Tutor takes the student through the cycle twice more, asking pertinent multiple-

Fig. 2. Title screen of the *Refrigerator Tutor* instructional software package.

choice questions at each point. The user receives comments on all answers, whether right or wrong, and is allowed to answer more than once. Since the software is for tutorial purposes only, no score is kept.

Since at this writing, the Tutor has been used only once by a sample of twenty students in the Spring 1998 semester, it is too early to assess its usefulness in the context of the course. Initial indications are that the Tutor is helpful in conveying the basics of the refrigeration cycle to students from a wide variety of backgrounds.

C. *Active Learning Techniques*

This course was developed with the assistance of the NSF-sponsored Science, Technology, Engineering, and Mathematics Teacher Education Collaborative (STEMTEC), a five-year project designed to improve science and technology education at the undergraduate level with the goal of increasing the number and quality of secondary-school science teachers. One way the STEMTEC project plans to do this is by introducing college-level instructors to some of the proven useful innovations which have been made in K-12 education. Many of these can be grouped under the category of "active learning" in which the conventional lecture format of a class is exchanged for one in which students take a more active part. Two ways that active-learning principles have been applied in "Engineering, The Human Enterprise" are the use of group projects and pyramid exams.

1. G*roup Projects*

The projects themselves encompass a variety of activities, from library research to laboratory-like experiences both inside and outside of class. Besides the food-spoilage experiment described above, two of the most well-received projects involve experimental investigations of low-temperature phenomena. In one project, student teams compete in the use of three different chemicals unknown to them (sodium chloride, calcium chloride, and potassium chloride) to make freezing mixtures with ice during a single class period. The team that achieves the lowest temperature receives an edible prize. In a second project project entitled “The Mystery Fluid,” students observe the clear liquid that forms on the outside of uninsulated metal cans filled with liquid nitrogen. Invariably, their first conclusion is that the clear liquid is water, despite the simultaneous appearance of solid frost next to the liquid. When they are informed that oxygen condenses at a temperature higher than the boiling point of nitrogen, they revise their initial hypothesis and draw the correct conclusion that the fluid is in fact liquid oxygen. They confirm this by holding a small magnet near a drop of liquid as it hangs from the bottom of the can. Liquid oxygen is sufficiently paramagnetic to be visibly attracted by the magnet.

The second project is cast in the form of a production difficulty at a food processing plant, and the students are asked both to determine the nature of the fluid and to come up with a solution of the problem. This encourages them to go beyond the scientific question, “What is the fluid?” to the technological question, “What can we do about the problem?”

2. *Pyramid Exam*

A pyramid exam is a multi-stage exam format which allows students to collaborate with each other during at least part of the exam process. Obviously, this method can blur the independent data on individual student performance which an exam is designed to produce. But used judiciously, a pyramid exam can be a fruitful learning experience as well as a means of assessing understanding. In the spring of 1998 we gave a pyramid exam after the second (technical) part of the course devoted to how a vapor-compression refrigerator works. The exam used multiple-choice, short-answer, and essay-format questions. One essay question was a classical one asked of generations of sophomore mechanical engineering students: “Suppose there is a room in a house that is so well insulated that no heat can enter or escape it. Suppose we put a refrigerator inside the room, plug it in to a power socket, turn it on, open the refrigerator door, and leave the room. What will happen to the temperature of the room as the refrigerator continues to run?”

After the individual exam papers were collected, the students worked on the same exam again in small groups. The grade of the group’s exam formed a portion of each group member’s overall exam grade. Finally, the entire class collaborated together on filling in the answers to the same exam on an overhead-transparency version. The score on this whole-class exam constituted ten percent of each student’s overall exam grade.

This shared-grade policy motivated a high degree of class participation in the discussion of how to fill out the answers on the whole-class exam. The process was moderated by a mature student, while the instructor sat by as an observer. When the open-refrigerator question came up, the debate over the answer became so intense that certain students began to voice feelings of personal animosity, and the instructor had to intervene to restore order!

IV. Curricular and Philosophical Issues

A. *Technological Literacy in the Curriculum*

The place of a technological literacy course such as this one in the college curriculum depends on the priorities of both the engineering department which offers it, and on the educational goals of the department's college or university as a whole. Although recruitment into engineering during the present generally favorable economic conditions is not as urgent a priority as it was a few years ago, a course about engineering for non-majors may introduce good students (including women and members of minority groups) to the idea of majoring in engineering when they otherwise would not have considered it. Informal surveys we have conducted show that at least a few students enroll because they want to learn more about engineering without committing themselves yet to becoming engineering majors. This possibility of increased recruitment is probably one of the few short-term advantages that an engineering department can hope to gain from offering a technological literacy course.

The second important factor in finding a place in the curriculum for technological literacy courses is the overall institutional attitude toward the importance of technological literacy in the general-education curriculum. Some colleges and universities explicitly require every student to take one or more courses having to do with technology, as opposed to pure science. In such an environment, developing technological literacy courses is fairly straightforward and often encouraged by administrative policy. The University of Massachusetts Amherst, a Research I institution that has a relatively small engineering college within a larger science and humanities campus, currently has no such explicit requirement. Although we have received encouragement in our technological literacy efforts from individuals within the administration, such favor has not yet made its way into the formal policy structure of the general-education curriculum.

In order for students to apply the credits earned in a course such as this one toward graduation, it must have an official general-education designation. In order to receive this designation, the course must meet certain qualifications under one or more of the institution's current general-education categories such as history, arts, literature, diversity, etc.

Procedures for obtaining one of these designations vary, but they all involve external review of the course proposal by administration and faculty committees before the course can be offered for general-education credit. Although "analytic reasoning" (meaning primarily mathematics and logic) is one category of general education at the University of Massachusetts Amherst campus which a technological literacy course could be designed for, we did not want to encourage the popular perception that understanding technology even a little requires one to learn advanced mathematics. Instead, we chose to develop the course for designation as an "interdisciplinary" course. Every undergraduate may apply at least three interdisciplinary course credits toward graduation, so in principle a course with this designation can be taken for graduation credit by anyone.

The process of applying for the general-education interdisciplinary designation took over a year. We redesigned the syllabus extensively after it was initially rejected by a faculty committee which felt the course was not sufficiently interdisciplinary. This redesign resulted in the positive feature of guest lecturers who treat topics in their area of expertise, but may have compromised the coherence of the course from the student's point of view. An instructor planning to offer a technological literacy course for the first time should become well-informed about the course approval procedure at the institution in question before assuming that it will be straightforward, easy, or quick.

B. *Philosophical Issues*

As aeronautical engineer and historian of technology Walter Vincenti has shown, the intellectual discipline of engineering has created a body of engineering knowledge which is clearly distinct from scientific knowledge. [6] Although modern engineering and technology depend upon science, they embody large fields of practice, technique, and theory which are not included in the disciplines of science per se. Engineering and technology also include aspects of economics, sociology, history, and even philosophy which are rarely if ever treated in standard undergraduate engineering curricula. Philosopher of technology Carl Mitcham has recently called upon engineers to philosophize as a way of both improving ethical behavior and increasing self-understanding. [7] One classical definition of the proper function of those within a university is to study the universe and everything in it. While it is true that bits and pieces of the wider field of engineering knowledge appear in science, history, sociology, and mathematics courses, a picture of engineering as an integrated and significant human activity seldom emerges from these treatments by other disciplines.

Technological literacy courses represent an opportunity to present the enterprise of engineering as an intellectual structure in its own right. At a time when college education is increasingly viewed simply as a means of increasing the earning power of individuals and nations, it may seem old-fashioned or even perverse to encourage studies about engineering and technology, not for practical and utilitarian reasons, but for cultural and philosophical ones. As a historical fact, the development of a subject as an independent intellectual discipline usually lags behind its appearance on the cultural scene. Individuals were doing modern scientific engineering long before there were many schools of engineering, and we can expect a similar lag to occur in the case of technological literacy. The closely allied field of the history of technology is scarcely forty years old, if one measures its age from the founding of the journal *Technology and Culture* in 1959. At present, a few U. S. universities have departments devoted to studies of technology and society from within the framework of engineering. Nevertheless, technological literacy is still viewed by most institutions of higher education as strictly optional, one of a long list of things it would be nice to teach their undergraduates, but by no means a necessity. To change this attitude at particular institutions, engineering professors will have to make a persuasive case for educating all undergraduates about the technological world around them, a case that must be presented repeatedly and persistently over a period of many years.

V. Conclusions

The course entitled "Engineering, The Human Enterprise" is one example of what can be done to explain the central importance of technology and engineering in present-day civilization to undergraduate students who do not plan to become engineers. With conventional engineering courses that teach engineering students how to do engineering, there is at least the hope of assessing the effectiveness of the educational process by measuring engineering ability. But a technological literacy course such as this one is even less amenable to assessment than conventional engineering courses, since the purpose is not to transfer a set of easily measured skills and abilities. We encourage clear, logical thinking in class discussions, presentations, and papers, but to no greater degree than in an ordinary humanities or science course.

One of the most important goals of any technological literacy course is to prepare students for responsible citizenship in an increasingly technological society. Unfortunately, for purposes of assessment this kind of outcome is not something that is easily measured over the short term, although some indications might be obtained through the use of attitude surveys before and after students take the class. Ultimately, the question of whether to teach technological literacy on a wider scale is rooted in society's consensus of what the educated person ought to know. Many of us who teach engineering agree that a higher level of public knowledge and understanding of technological issues would make the world a better place. "Engineering, The Human Enterprise" is one such attempt in a long-term project which is far from over.

VI. Acknowledgments

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