2006-744: TECHNOLOGICAL LITERACY AND ENGINEERING FOR NON-ENGINEERS: LESSONS FROM SUCCESSFUL COURSES.

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Technological Literacy and Engineering for Non-Engineers: Lessons from Successful Courses.

Abstract

The engineering profession is united in calling on all Americans to understand and appreciate the central nature of technology in our daily lives. This call for technological literacy has resulted in some action; however, the national efforts are thus far directed largely toward the pre-college K12 population. Efforts to address the broad understanding of all types of technology, not just information technology, often proceed under different names including: technological literacy, engineering for non-engineers, engineering for everyone, and engineering as a liberal art. The last major initiative to address technology literacy among undergraduates was the Sloan Foundation's New Liberal Arts Program. This effort ended nearly two decades ago in the mid nineteen eighties just as the Internet was becoming widespread, the audio compact disk was a still a novelty, and the vast array of digital devices which now common place were just appearing in crude form. In light of these developments, it is time to reconsider technological literacy among undergraduates. While activity by engineering educators has not been widespread, a number of individuals have worked steadily on aspects of the topic and have accumulated encouraging results. This work will review representative technological literacy courses taught in recent years. The review will emphasize lessons learned from successful technological literacy courses. Also presented will be similarities and differences in learning objectives and student outcomes, assessment tools and techniques, strategies for establishing technological literacy courses, and factors affecting implementation in different types of institutions including community colleges.

Background

A workshop on the technological literacy of undergraduates was sponsored by the National Science Foundation (Division of Undergraduate Education) and convened at the National Academy of Engineering on April 18-19, 2005. This workshop sought to identify and define the current research issues regarding the broad understanding of technology by all undergraduates. The workshop format consisted of a dozen presentations by faculty having individually implemented technological literacy courses at their home institution. The major features of these courses are summarized below.

The technological literacy courses presented establish that the subject can be implemented successfully across a wide range of undergraduate institutions. The modest number of campuses offering such courses, estimated at perhaps two dozen, indicates opportunity and need for expansion in order to increase the technological literacy of US undergraduates as both NAE and NSF have recommended.

Among the current courses, several have been taught for more than ten years, others are as recent as one year. Class size varied from ten to several hundred, according to campus. The highest enrollment examples were found at campuses where the technological literacy course fulfilled a technical or science distribution requirement for non-engineering students. Thus the design of technological literacy courses to meet local distribution and curricular needs appears important for gaining course permanence, and in aiding the spread of technological literacy instruction.

Most of the existing courses were established before the recent efforts to by the National Academy of Engineering (NAE)[1] and the International Technology Education Association (ITEA)[2,3] to define technological literacy and establish standards for this topic. The course curricula were determined by the individual instructors. In most cases, elements of the NAE and ITEA standards are incorporated into these already existing courses. Because the standards are of broad scope, not single course includes all.

Review of Technological Literacy Courses

The following examples illustrate that technological literacy courses have been successful across a wide range of undergraduate institutions types.

"Designing People," James Baish, Bucknell University[4].

In this foundation seminar, students explore the design process. They study the elements of past designs and engage in design themselves. They work as individual designers and as part of a design team. They ill undertake a design project to address an important human need in today's society. A major segment of the course focuses upon the evolution of the automobile as an example of human design. Questions about the real versus created needs are asked. The interaction of design with economics, social structure, politics and engineering capabilities is studied. The elements of style and aesthetics are assessed including the presence of gender differences. Several field trips are held to museums in order to see and evaluate past designs, and to modern manufacturing facilities to see how design is employed today.

It was found that design projects were technically accessible to all types of students without the need for highly specialized quantitative methods. Rule-of-thumb techniques made the design process accessible to math-averse students. While a challenge, limited mathematics background was not a barrier. The course appealed to a broad range of students. Meeting a university degree requirement was found to be an important element in establishing enrollments.

"Converging Technologies," Robert Balmer, Union College[5,6].

Converging Technologies are the new and often unforeseen technologies that appear at the boundaries between of traditional fields of study. Starting in 2001, Union College began implementation of a Converging Technologies initiative. Since then approximately 30 new courses have been introduced. In each interdisciplinary area, courses are open to both engineering and liberal arts students. Course topics include: Bioengineering and Computational Biology, Entrepreneurship, Mechatronics, Nanotechnology, Neuroscience, Pervasive Computing, and Science, Medicine and Technology in Culture

The Converging Technologies Program is well integrated into Union College curricula. Notable results include: creation of approximately 30 new courses, creation of one new converging technologies major and four converging technologies minors, integration of converging technologies material into numerous existing courses, appointment of a converging technologies director and designation of a building to be remodeled as a Center for Converging Technologies, establishment of an external converging technologies advisory board. This program has received the support of the college Board of Trustees and is now considered one of the pillars of excellence of Union College.

"How Things Work, Physics 105 and 106," Louis Bloomfield, University of Virginia[7,8]

This course for non-science majors introduces physics and science in everyday life. It considers objects from our daily environment and focuses on their principles of operation, histories, and relationships to one another. Physics 105 is concerned primarily with mechanical and thermal objects, while Physics 106 emphasizes objects involving electromagnetism, light, special materials, and nuclear energy. They may be taken in either order.

The course was designed for non-scientists and built around everyday objects. The course became exceptionally popular. For more than a decade, 500 students took the course each semester, however enrollment is now capped at 200 students. The impact of the course *How Things Work* has been widespread. At the University of Virginia, many non-science students who would otherwise have no exposure to physics are now learning physics and finding it useful. There is less fear of physics indicating a significant cultural change. Physics has become a valued part of the university curriculum, and other physics courses are flourishing. The *How Things Work* textbook which grew out of the course has been used in over 200 other colleges and universities.

"Science at Work: Technology in the Modern World," Kate Disney, Mission College[9]

This course is designed for students of all disciplines who are interested in principles and applications of science. Students experiment with technological applications to discover scientific principles. Concepts of science discovered through experimentation and observation include: force, work, and power; the conversion of energy and the transmission of power; Newton's Laws; thermodynamics and heat engines; Faraday's Law of induction; Radiation; atomic mass energy; and materials science. Students dissect an engineering system after the instructor provides a presentation and/or demonstration or the related scientific theory. Experiments enable students to verify or disprove their initial hypothesis as to how the system functions and employs science. There is a Credit/ No Credit option

"Fuel Cell Systems," Camille George, University of St. Thomas10

A discovery-oriented pedagogy devoted to all aspects of fuel cells: types, operation, design, safety, economics, policy & implementation. The class examines the chemistry, physics, design, system integration, energy analysis and cost of fuel cells. Considerable time is spent on hydrogen generation, storage & distribution. Class follows the 'inquiry- based learning' pedagogy, not the traditional lecture/exam model. Anyone interested in energy policy & the new hydrogen economy is invited to participate. No prerequisites. All interested students are encouraged to enroll.

"The Hidden World of Engineering," William Hammack, University of Illinois at Urbana-Champaign[11]

Simple objects shape our lives, yet are engineering masterpieces. To unveil this hidden world, the course uses a humanistic approach. Designed to appeal to all majors, it uses human stories - filled with failures and triumphs - to reveal the methods of engineers. The course enchants with tales of ancient steel making, today's pop cans, huge stone monuments, and salt. The course seeks to change how a student looks at his or her world. Several sessions focus on women engineers and the environment.

This course for non-engineers attracts 60% business majors and 40% from other majors. An emphasis is placed on engineering decisions or choices: Why did an engineer decide to design an object in a particular way? Bill Hammack also created the *Engineering and Life* program on public radio which reaches beyond the classroom to a mass audience.

"Science and Technology of Everyday Life," John Krupczak, Hope College[12,13]

This course studies the wide variety of technology used in everyday life. Modern society would not exist without the aid of technology. We depend upon technological devices for communication, food production, transportation, health care and even entertainment. The course objectives are to develop a familiarity with how various technological devices work and to understand the scientific principles underlying their operation. Topics covered include the automobile, radio, television, CD players, microwave ovens, computers, ultrasound, and x-ray imaging. Concepts from basic science are introduced as they appear in the context of technology. Laboratory projects include construction of simple objects such as radios, electric motors, and a musical keyboard.

Since its introduction in 1995, this course has been taken by more than 1000 non-engineering students, participants were 60% women and 26% preservice teachers. To evaluate student outcomes, the Motivated Strategies for Learning Questionnaire (MSLQ) was applied. Statistically significant increases were found in intrinsic motivation, task value, and self-efficacy. A decrease in test anxiety was also found. These results show that non-engineering students can have increased motivation for learning science and technology, increased perceived value for science and technology, and increased self-confidence about learning science and technology.

"The Digital Information Age," Roman Kuc, Yale University[14,15]

An introduction to information transmission and storage and their impact on society. Technological issues and trade-offs that affect the design of communication systems. The binary number system, elementary computer logic; digital speech and image coding on compact disks; information transmissions-from touch-tone telephones to modems and faxes to World Wide Web; UPC bar codes, and a glimpse into the future. Projects include implementing a single digital system and Web pages. Intended for students in the humanities and social sciences and for freshmen considering an electrical engineering major. No prerequisites other than a working knowledge of elementary algebra.

Course enrollment reached 500 students per year making this one of the largest and most popular classes at Yale. Positive student response includes a sense of empowerment through having developed an understanding of how information systems work. Many of the students reported this the most worthwhile course they had taken at the University.

"The Engines of Our Ingenuity," John H. Lienhard, University of Houston[16-18]

The Engines of Our Ingenuity was originally a course at the University of Houston and is now a daily radio program that is carried nationally on some 46 Public Radio stations as well as other markets. Associated with it is a website that gets approximately third of a million page hits per week and is widely used in schools[31].The radio program that tells the story of how our culture is formed by human creativity.

Engineering in the Modern World," Michael Littman and David Billington, Princeton University[19].

Among the works of concern to engineering are bridges, railroads, power plants, highways, airports, harbors, automobiles, aircraft, computers, and microchips. Historical analysis provides a basis for studying urban problems by focusing on scientific, political, ethical, and aesthetic aspects in the evolution of engineering over the pasts two centuries. The precepts and the papers will focus historically on the social and political issues raised by these innovations and how they were shaped by society as well as how they helped shape culture.

The class attracts many first and second year students. Engineering students can take the course to satisfy a "historical analysis" graduation requirement. The course is conducted using the language of science and mathematics, including heavy use of formulas. Despite the use of mathematics and a laboratory component, about one-fourth of all Princeton non-science majors take this class.

"Electrical Machines and Information Technology Systems," Deborah Mechtel, United States Naval Academy[20]

Modeling and analysis techniques are applied to rotating electric machinery. Basic principles of digital logic circuitry and computer architecture are introduced. The principles of analog and digital communications are presented, including common digital modulation techniques. Link budget analysis and satellite communications principles are presented. Other topics include network topology, connectivity, routing, queing, bandwidth, spectrum utilization, the OSI Modele, TCP/IP, and the Internet.

All students at the Naval Academy, regardless of their major, must take two electrical engineering courses. These courses are taught to more than 600 students each year. The results show that students across range of majors can achieve level of knowledge comparable to engineering students. Because the material is strongly related to naval applications, midshipmen see this knowledge as important to them. All students have necessary prerequisite material since all students also have three semesters of calculus before taking class. Success is also based on a supportive laboratory environment and class sizes that facilitate individual attention if needed. Students respond positively to a obtaining an in-depth understanding of electrical engineering topics. A non-engineering student learning about radar remarked that: “I have been wanting to know this for so long,” a not infrequent student response.

“Technological Literacy: How Things Work,” David Ollis, North Carolina State University[21]

Lecture survey on evolution and current status of thirteen modern technologies involving electricity, information, sound, light, imaging, recording, engines, materials, and language codes. The laboratory allows both lecture-demonstrations and team-based explorations of modern technologies. Lab topics include cell phones, electric and acoustic guitar, FAX machines, optical fibers, engines, Internet search engines, CD systems, photocopiers, video cameras and digital cameras, satellite TV, and water purifiers. Lectures and labs together provide context, content, and contraption. Case examples reported as written papers.

The course attracted students from Colleges of Humanities and Social Sciences, Art and Design, Education, and Management. Organization of the laboratory portion of the course demonstrated how to effectively share equipment between a technological literacy course and engineering department use. This sharing of resources increased the use efficiency of both space and equipment. The course demonstrated a novel, multi-dimensional approach to technology literacy as a new format for delivery of this topic: each topic is approached through study of device historical origin and technical evolution, description of principles and key operations of the modern device, and the opportunity to use, dissect and reassemble the device at a basic level, sufficient to encounter major process paths.

“Technology 21”, Albert J. Rosa, University of Denver[22]

This is a course for leadership in the new millennium. It prepares students to make wise technological decisions. Decisions on technology that affect all of us are rarely made by scientists or engineers, but rather by business people and politicians who often are swayed by emotion, popular, opinion, misconceptions and/or mistrust of technology. This course provides students with sufficient background to help them make smart technological decisions. The first two quarters help students understand the basic resources available to develop technology: energy, materials and information. These resources comprise the fundamental building blocks of a modern technological society. The last quarter allows students to practice making smart technological decisions on a national or global issue.

This course has been taught successfully for 14 years. Initially an experiment, the course has become fully institutionalized and is seen as an important offering by the Department of Engineering. A variety of different instructors have taught the course with success. The course is able to attract students from liberal arts, business, law, and other non-technical disciplines. Enrollment is capped at 90 students with a considerable waiting list. The department has also been successful in attracting a diverse array of experts from outside the university to assist in their areas of expertise.

"Electrical Signals and Systems," Albert J. Rosa, University of Denver, (formerly of the United States Air Force Academy).

This course is an introduction to signal analysis and electronic system design. Topics include signal representation, signal analysis in the time and frequency domains, digital systems, basic circuit analysis, and realization of electronic functions used in the design and operation of Air Force instrumentation, communication, and digital signal processing systems.

This course was originally created in 1979 and is required of all non-engineering students at the Air Force Academy. It has evolved along with the technology over the past 25 years, but is still meeting the same basic goals of informing all cadets of the role that electrical engineering technology will have in their lives in the Air Force.

"Innovation, Invention, and Technology," Tarek Shraibati, California State University Northridge[23]

The course is an exploration of the history, processes, methods, and creators of technological innovations and invention. Global contributions, creator diversity, and technological failures are addressed. Critical assessments of technological innovation and invention are developed.

"Introduction to Computer-Aided Graphics Tools," Tarek Shraibati, California State University Northridge[23]

Introduction to the use of computer-aided (CA) graphics tools. Development of skills and techniques in graphical, pictorial and rotational representation. Students will be able to work on an individual project tailored to meet the needs of their field of study, and post their project on the Web. (Available for General Education, Section E, Applied Arts and Sciences; not available for credit towards an engineering degree)

This course has been successful at a culturally diverse, comprehensive regional university in which many of the students are the first members of their families to attend college. The course is successfully established as a regular offering at the university. Students taking the course are drawn from a variety of majors including: graphic design, art, math, urban studies, journalism, biology, health science, English, history, speech communications. Many of the students in the class are freshmen. In a recent survey, 41% of the students indicate they would be interested in taking another course of this type.

"Technology and the Human Built World," Krishna Vedula, University of Massachusetts-Lowell.

Humans have been called the animals which make things and at no time in history has that been so apparent as the present. Today, every human activity is dependant upon various tools, machines and systems, from growing food and providing shelter to communication, healthcare, entertainment and security. The average citizen, therefore, needs to be more knowledgeable of the history and nature of technology that sustains the modern world. This will ensure that the public is engaged with the decisions that help shape its technological future.

In this course, students will develop an understanding of the Nature of Technology including relationships among technologies and the connections between technology and other fields. Students will develop an understanding of Technology and Society including the cultural, social, economic and political effects of technology; effects of technology on the environment; role of society in the development and use of technology; and influence of technology on history. Students will develop the abilities to apply the design process, use and maintain technology and assess the impact of products and systems. Students will develop an understanding of the designed world including selecting and using medical technologies, agricultural and biotechnologies, energy and power technologies, information and communication technologies, transportation technologies, manufacturing technologies and construction technologies.

"Engineering for Non-Engineers," Larry Whitman, Wichita State University[25]

An introduction to the engineering discipline using hands-on exercises and demonstrations using LEGO Mindstorms. Technical and practical aspects of aerospace, computer, electrical, industrial, manufacturing, and mechanical engineering are presented. Intended for freshman and sophomore non-engineering students who want to understand how engineering impacts their lives.

The class targets students who are not "techies" and are not intending to become engineers. The versatility of LEGO Mindstorms is exploited to serve as a common platform to carry out projects representative of several different engineering fields including: mechanical, electrical, industrial, aerospace, and programming.

Overview of Course Structure

The technological literacy course represented by the presenters contained substantial variety and focus in their subject mater and approaches. This character is illustrated best through the simple course summaries presented below (alphabetical by instructor). Table 1 summaries principal components of some technological literacy courses.

Table 1: Technology Literacy Course Summary: Principal Components.

Instructor	Semesters	Units	Lectures/wk	Laboratory	Demos	Co- taught
Baish	one	1	3	no	yes	w/eng'g and liberal arts, sociology
Balmer	one	3	3	some	some	w/liberal arts faculty
Bloomfield	one	3	3	no	yes	no
Hammack	one	3	2	no	no	no
Krupczak	one	4	3	yes	yes	no
Kuc	one	3	2	yes	yes	no
Mechtel	two	4	3	yes	yes	with other engineering
Littman/ Billington	one	3	2	yes	yes	yes
Ollis	one	3	2	yes	yes	no
Rosa	3 quarters	4/q	3	yes	yes	w/other engineering
Shraibati	one	3	3			
Whitman	summer	3	4	yes	yes	yes

Course Theme Compared to Instructor Expertise

Inspection of the titles and contents of these courses reveals some similarities and many differences in content. A much clearer picture arises if we recall John Truxal's advice: "Teach from what you know'" The table below shows the clear correlation between the disciplinary training of the instructor, and the major theme(s) of each course summarized above.

Table 2: Correlation of Research Interests with Technological Literacy course themes.

Instructor	Engineering Discipline	Dominant Course Theme
Lienhard*	Mechanical	Engines of Our Ingenuity
Bloomfield	Physics	Physics of Everyday Life
George	Mechanical	Hydrogen Economy – Fuel Cells
Kuc	Electrical	Digital Information Age
Krupczak	Mechanical	Mechanical,Electrical items
Mechtel	Electrical	Electrical, computer eng'g; digital communication
Littman/ Billington	Physics/ Civil	Civil infrastructure
Balmer	-----	(multiple course & fac.)
Ollis	Chemical	Photophysics and Photochemistry in many devices

*Course last taught in 2000. Theme is text title.

Learning Objectives

Within the context of engineering education, student learning objectives are important as they provide the basis for outcome-based assessment: did student learning result in achievement of the desired outcomes? Four sample student learning objectives are provided at a level of detail suitable for assessment and evaluation. These are summarized below. While some commonality exists, the diversity of student learning objectives is appreciable, reflecting lack of an accepted definition for "Technological Literacy." It is expected that recent NAE and ITEA technological literacy standards may promote convergence on this issue.

Student Learning Objectives (four examples)

1. Technology and the Human Built Environment (K. Vedula)

Students will develop:

- an understanding of the nature of technology including relationships among technologies and the connections between technology and other fields.
- an understanding of Technology and Society including the cultural, social, economic and political effects of technology; effects of technology on the environment; role of society in the development and use of technology, and influence of technology on history.
- abilities to apply the design process, use and maintain technology and assess the impact of products and systems.
- an understanding of the design world including selecting and using medical technologies, agricultural and biotechnologies, energy and power technologies, information and communication technologies, transportation technologies, manufacturing technologies and construction technologies.

2. Engineering in the Modern World (M. Littman)

Students will

a. develop an understanding of the transformation of the modern world through engineering (e.g., agriculture to industry, isolated to connected, etc.)
b. define modern engineering through examples of innovations (structures, machines, networks, processes from the start of the industrial revolution to the present); understand the historical context (political, social, economic) for engineering innovation; understand the underlying science; recognize the influence of technology on society as expressed by artists (painters, photographers, writers)
c. develop an understanding of the key people who were responsible for engineering innovations-what they did, when they did it, and why they were successful.

3. Science and Technology of Everyday Life (J. Krupczak)

Students will:

a. understand the basic principles of electricity, magnetism, light, sound, and mechanics as applied in familiar technology. Know the fundamental scientific and engineering principles applied in familiar technology.
b. understand key technological inventions and innovations and the ideas embodied in these technological devices
c. develop an ability to find and interpret technical information as it pertains to issues of importance to the non-engineering student. Be able to evaluate and combine technical information from several sources. Demonstrate an ability to build upon a knowledge base developed in the class.
d. be able to transfer knowledge to new contexts beyond the classroom.
e. increase interest, motivation, and self-efficacy for understanding science and technology.

4. Technology Literacy: How Stuff Works (D. Ollis)

Students will:

a. develop a basic vocabulary and conceptual framework for describing the technical and historical origins of modern technological devices
b. explain the conceptual operating bases of current and prior technologies which address similar societal needs
c. use and dissect devices to develop understanding of the relationships between technical subsystems of a device (e.g., the optical, electrical, and mechanical subsystems of a facsimile (FAX) machine), and their influence on device design and operation.
d. develop and understanding of the impacts (technical, economic) of a device in a given context, through lecture and individual analytic written papers.

These four examples of learning objectives all relate strongly to Nan Byar's 1998 proposed definition of technology literacy[24] , and her associated expected outcomes:

"Technology Literacy: A Working Definition: The ability to understand, intelligently discus and appropriately use concepts, procedures and terminology fundamental to the work of (and typically taken for granted by) professional engineers, scientists, and technicians; and being able to apply this ability to:

- critically analyze how technology, culture and environment interact and influence one another
- accurately explain (in non-technical terms) scientific and mathematical principles which form the basis for important technologies
- describe and, when appropriate, use the design and research methods of engineers and technologies,
- continue learning about technologies, and meaningfully participate in the evaluation and improvement of existing technologies and the creation of new technologies[24] "

Course Materials

Teaching materials are an item of concern for those considering launching a technological literacy course. The textbooks used in some of the individual courses are listed below. These again indicate a wide variety of usage, and illustrate the relative lack of central focus among the current technology literacy courses.

Table 3: Sampling of Texts Used Within Conference Courses on "Technology Literacy."

Course	Book
Explore Engineering	(instructor materials)
Technology and Human values	Volti, Society and Technological Change Teich, Technology and the Future
The Hidden World of Engineering	(instructor materials)
Science & Tech of Everyday Life	Macaulay, The New Way Things Work Bloomfield, How Things Work
The Digital Information Age	Kuc, The Digital Information Age
Technology and Western Culture	(multiple sources)
Electrical Fundamentals and Applications	Boyles, Introductory Circuit Analysis Tokheim, Digital Electronics Frenzel, Electronics Communication Systems
Engineering in the Modern World	Billington, Innovators
Technology 21	(multiple)
Women in Mathematics and Science	(instructor materials)
Technology and the Human Built World	Hacker & Berghardt, Technology Education - Learning by Doing Constable and Somerville, A Century of Innovations

Assessment Tools and Techniques

Most existing courses use several assessment tools and techniques. The average number of tools and techniques per course was about 6, probably larger than the average number used within a typical engineering course. Shown in Table 4 are the most common along with additional individual approaches indicated in category (i), and includind individual or team-written term papers, web-based projects, lab reports, robot simulations, and book analyses.

Table 4: Summary of Assessment Tools and Techniques.

	Method	YES	NO
a.	Pre/post course student survey	5	5
b.	Student interviews	7	2
c.	Formative course assessment	7	4
d.	Summative course assessment	9	3
e.	Written exams	10	2
f.	Oral presentations	8	3
h.	Lab team performance	9	2
i.	Other: individual (1) or team-based (1) term paper Web-based projects (1), lab reports (1) robot simulations(1), book analyses(1)		

The lack of a consensus definition for technological literacy noted earlier makes comparison of evaluations among different courses awkward. Similarly, the relative lack of student learning objectives also diminishes the potential effectiveness of the evaluations for other courses presented, since the student themselves may not have been aware of the instructor expectations in all cases.

Conclusions

The variety of successful technological literacy courses presented establishes that such courses can be implemented across a wide range of different types of undergraduate institutions. The technological literacy courses represented contained substantial variety and focus in their subject matter and approaches. This variety in actual course content, and widespread success spanning diverse campuses, demonstrates that non-engineering students can respond enthusiastically to technological literacy courses.

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