AC 2008-807: A FRAMEWORK FOR DEVELOPING COURSES ON ENGINEERING AND TECHNOLOGY FOR NON-ENGINEERS

John Krupczak, Hope College
Professor of Engineering

Timothy Simpson, Pennsylvania State University
Professor of Mechanical Engineering

Vince Bertsch, Santa Rosa Junior College
Professor of Engineering and Physics

Kate Disney, Mission College
Engineering Instructor

Elsa Garmire, Dartmouth College
Sydney E. Junkins 1887 Professor of Engineering

Barbara Oakley, Oakland University
Associate Professor of Engineering

Mary Rose, Ball State University
Assistant Professor, Department of Technology

A Framework for Developing Courses on Engineering and Technology for Non-Engineers

Abstract

All Americans need to better understand the wide variety of technology used everyday. The need for technological literacy has never been greater at both an individual and national level. Creating a population with a more empowered relationship with technology will require a significant and widespread initiative in undergraduate education. Courses and materials that are easily adoptable in diverse and varied institutional environments will facilitate this effort. In two reports: *Technically Speaking: Why All Americans Need to Know More about Technology* (2002), and *Tech Tally: Approaches to Assessing Technological Literacy* (2006), the National Academy of Engineering (NAE), has outlined the characteristics of a technologically literate citizen. The International Technology Education Association (ITEA) and the American Association for the Advancement of Science (AAAS) have also developed standards defining technological literacy. Recognizing the need for standardized and readily adoptable undergraduate courses on this topic, the NSF supported a working group lead by the American Society for Engineering Education (ASEE) Technological Literacy Constituent Committee. This group met on March 26-27, 2007 and adopted four models to serve as standardized courses on technology. In this work, a framework for specific course outlines consistent with the content areas established in *Tech Tally* of: technology and society, design, products and systems, and technology core concepts and the ITEA technology topic areas was created. To balance the need to accommodate the diverse requirements of curriculum committees on varied campuses, the framework offers flexibility to faculty in configuring courses within each proposed model while still accomplishing the intent of the standards. This framework is intended to form the organizational infrastructure for creating a repository of course materials and an online community for course developers and instructors.

Overview

Technology affects nearly every aspect of our lives, and informed citizens need an understanding of what technology is, how it works, how it is created, how it shapes society, and how society influences technological development. Technological choices influence our health and economic well-being, the types of jobs and recreation available, even our means of self-expression. How well American citizens are prepared to make those choices depends in large part on their level of technological literacy. At a recent NSF Workshop at the National Academy of Engineering (NAE) participants sought to create a set of standard models for teaching technological literacy courses [1,2]. As part of that workshop, a framework for evaluating courses on technological literacy and providing a useful context for discussing standard models for technological literacy courses was developed. Such a framework is not only critical for developing effective technological literacy courses but is also a pre-requisite for developing standard course models.

The proposed framework will help faculty develop expertise in adapting existing innovative course materials and standards for defining technological literacy and incorporating them efficiently into their own courses.

What Is Technological Literacy?

In their 2006 report, *Tech Tally* [3], the NAE defined technological literacy as "an understanding of technology at a level that enables effective functioning in a modern technological society". This is consistent with E.D. Hirsh's general definition of "literacy" as "information that is taken for granted in public discourse" [4]. *Tech Tally* was a follow-up to a 2002 report by the NAE entitled, *Technically Speaking: Why All Americans Need to Know More about Technology*, which describes the importance of being literate about technology in the 21st century [5]. Both NAE reports emphasize that technology, in a broad sense, is any modification of the natural world made to fulfill human needs and wants. This includes not only its tangible products, but also the knowledge and processes necessary to create and operate those products. The infrastructure used for the design, manufacture, operation, and repair of technological artifacts is also considered part of technology, in its broadest sense.

Parallel efforts have been underway for over ten years to develop Educational Standards and Benchmarks to define what K-12 students need to know and be able to do about this kind of technology. In 1993, the American Association for the Advancement of Science (AAAS) published, *Project 2061: Benchmarks for Science Literacy* [6] and in 1996 the *National Science Education Standards* were published by the National Academies Press [7], both of which contained a section devoted to technology. In 2000 the International Technology Education Association (ITEA) published *Standards for Technological Literacy: Content for the Study of Technology* [8] with the intent of encouraging educational curricula that would provide technological literacy to K-12 students

In *Tech Tally*, NAE identified three major components, or cognitive dimensions, related to technological literacy: *knowledge, capabilities*, and *critical thinking and decision-making*. As defined in their report, "The '*knowledge dimension'* of technological literacy includes both factual knowledge and conceptual understanding. The '*capabilities dimension*' relates to how well a person can use technology (defined in its broadest sense) and carry out a design process to solve a problem. ...The final dimension – the '*critical thinking and decision-making*' dimension – has to do with the student's approach to technological issues" [3]. This dimension enables the individuals to ask questions about risks and benefits when introduced to a new technology, and to participate in discussions and debates about the uses of that technology. In addition to these three cognitive dimensions, four content areas were defined: (1) technology and society, (2) design, (3) products and systems, and (4) characteristics, concepts, and connections. Finally, an assessment matrix was proposed that combined the four content areas (the rows of the matrix) with the three cognitive dimensions (the columns of the matrix), and it is this matrix that spurred the development of the proposed framework (see Section 3).

Simultaneously, the International Technology Education Association (ITEA) also developed a set of standards (ITEA 2000) for technological literacy, which was published in their report entitled, *Standards for Technological Literacy: Content for the Study of Technology* [8]. The

ITEA 2000 Standards are divided into five main categories that sub-divide into 20 specific standards:

1. Understanding the Nature of Technology
2. Understanding of Technology and Society
3. Understanding of Design
4. Abilities for a Technological World
5. Understanding of the Designed World.

While the ITEA 2000 standards address K-12 students, it was found that the detail of these standards was helpful in categorizing or classifying content areas that might appear in technological literacy courses for undergraduates. As such, the proposed framework integrates these disparate attempts to define technological literacy and reconciles the overlap between the NAE and ITEA approaches, but first we review other related work in this area.

Engineering and Technology Courses for Non-Engineers.

The engineering education community has begun developing a broader scope, becoming active beyond its traditional boundaries. Engineers have embraced the need to increase the awareness and understanding of engineering as a career by initiating a number of programs aimed at the K-12 audience. A recent example is the American Society for Engineering Education's (ASEE) publication, *Engineering Go For It,*[9] and a website [10] aimed at a K-12 students and teachers. Most major engineering societies now have outreach activities for K-12 [11-14]; meanwhile, ITEA is working to develop program and assessment standards, and curriculum materials for the K-12 audience [15]. In the midst of these efforts, Engineering departments offering courses on technological topics for non-engineering students remain relatively uncommon[16].

The recent history of efforts to address the technological literacy of undergraduates can be traced back to 1982 when the Alfred P. Sloan Foundation launched the New Liberal Arts Program (NLA). The goal was to improve the quality of education that undergraduates receive in the areas of technology and quantitative reasoning [17-19]. The Sloan Foundation sponsored development of a variety of courses on technological topics for non-science majors. The NLA Program broke new ground in establishing technology as the intellectual peer of science at the college level; however, the experience of the NLA highlighted the difficulty in migration of courses beyond the founding instructor and campus, and sustaining course offerings after the initial funding period [20].

Since the end of the NLA, some engineering educators have worked steadily on aspects of addressing the broad understanding of technology by undergraduates [21-23]. While the total number of courses reported has been limited [24-53,61-63], results have been noteworthy. Many courses have been successful in attracting substantial enrollments of non-engineering students and existing as long-term departmental offerings [25-29,35-41,44-46,52,53]. Some specific illustrative examples include *Technology 21*, developed at the University of Denver [52]. Non-engineers study a technological controversy and develop a policy recommendation. The course has been offered by the Electrical Engineering Department for more than 14 years and has been taught by nearly all departmental faculty. The Converging Technologies Initiative at Union

College has lead to nearly 30 new or modified courses at Union since 2002 on interdisciplinary technological topics such as pervasive computing and nanotechnology [25,35]. At California State University Northridge, the Manufacturing Systems Engineering Department has taught Computer-Aided Design to campus-wide constituency for a decade [53]. Dartmouth College has had a requirement since 1992 that every student take a course in Technology and/or Applied Science. The majority of these courses are taught by engineering faculty, and some have enrolled as many as 150 students [54].

In parallel with these efforts by engineering departments to serve non-engineers, some college and university physics departments have reconfigured their courses for non-majors to emphasize technological topics. Representative examples include Dudley and Bold's, "Top-Down Physics" [55], Watson's "The Science Concepts behind High Technology" and "Silicon, Circuits, and the Digital Revolution" courses [56]," and the course and textbook by Bloomfield entitled *How Things Work: The Physics of Everyday Life* [57,58]. This approach of technologically-themed and application-oriented science courses for non-science majors incorporates perspectives more akin to engineering than traditional physical science courses. These recent efforts at motivating the learning of physics by understanding modern technology stand in distinct contrast to earlier classic works such as *Physics for the Inquiring Mind* [59] and *Physics for Poets* [60], which avoided technological applications and emphasized philosophical questions and natural phenomena.

These developments illustrate that demand and interest exist among the non-engineering undergraduate population for courses on technological issues. It also demonstrates that engineering faculty can develop and teach courses on technological topics to non-engineering students. The successful courses taught by engineers span the entire spectrum of institution type and student demographics. They represent diverse campus environments including large state universities [45-48,51], small private colleges [29,37], technically oriented institutions [49,50], highly selective schools [26,27,40,43], comprehensive universities [28,44], schools serving working adults [16], and two year institutions [63,64]. The background of the instructors represent the major engineering disciplines including chemical [48], civil [26-28,44], electrical [34,36,40], materials [45,46,61] and mechanical engineers [24,29,31,37]. However, a common feature of nearly all successful technology courses is the need to satisfy some component of the college or university general education graduation requirement and to be adapted to instructor interests or other aspects of local institutional conditions [65,66].

To help define the research issues regarding the broad understanding of technology by all undergraduates, a workshop on the technological literacy of undergraduates was sponsored by the NSF Division of Undergraduate Education and convened at the NAE in April 2005. The 42 participants included individuals who had successfully implemented courses on technological literacy for undergraduates as well as representatives from other engineering and non-engineering disciplines. The most important recommendation from the group at the workshop was: "There is a need for a best practice collection of easily adopted materials." [67,68].

Most of the existing technological literacy courses were established before the recent efforts by the NAE and the ITEA to define technological literacy and establish standards for this topic. Individual instructors determined course syllabi based on their expertise and level of comfort with the material. As part of the 2005 NSF/NAE Workshop, participants found that elements of the NAE and ITEA standards had been incorporated into most of the existing courses; however, no single existing course included all of the standards due to their breadth. With this came the realization that no single standard course model could be developed for a course on technological literacy; instead, four standard course models were proposed and slated for development as part of the follow-on NSF/NAE Technological Literacy for Undergraduates Workshop, which was held in March 2007 [1,2]. The four standard course models were: (1) Technology Survey Course, (2) Technology Focus Course, (3) Technology Design Course, and (4) Technology Critique, Assess, Reflect, or Connect Course. The proposed framework was created to serve not only as a guide for developing these standard course models but also as a method for evaluating and benchmarking existing technological literacy courses.

Description of the Proposed Framework

The proposed framework was developed by a team at the 2007 NSF/NAE Workshop on Technological Literary of Undergraduates [1,2]. The framework is currently embodied in the form of a 2D matrix that maps content areas – called *cross-cutting concepts* – to different *technology topic* areas, as shown in Figure 1. The technology topic areas – the columns in the matrix – are derived from the "Designed World" categories defined by the ITEA 2000 Standards [8] and include an additional "Other" category for areas that the faculty felt were missing from ITEA's Designed World (e.g., space technology, military technology, materials, entertainment systems).

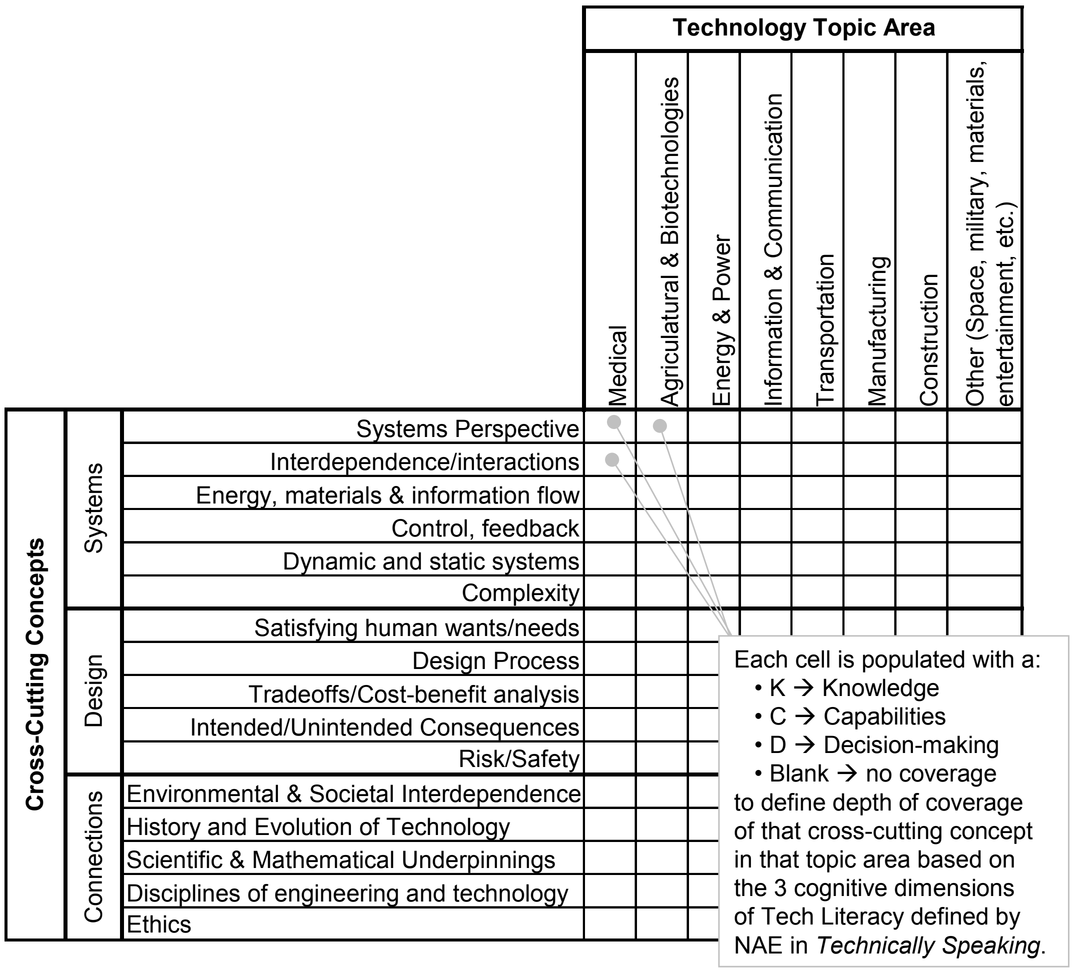


Figure 1. Proposed Framework: The Tech Lit Course Evaluation Matrix

The rows of the matrix in Figure 1 are specific cross-cutting concepts group under the broader headings of Systems, Design, and Connections, which are also based loosely on the four content areas defined in *Tech Tally* [3]: (i) Technology & Society, (ii) Design, (iii) Products & Systems, and (iv) Characteristics, Core Concepts, & Connections. Essentially, areas (i) and (iv) were grouped together while it was understood that Systems in the matrix included both products and systems as defined in area (iii).

Having defined the rows and columns, each cell in the matrix can now be populated with one of four values as noted in Figure 1 to indicate the depth of coverage of that cross-cutting concept in each technology topic area:

1. K → Knowledge, i.e., the course will provide knowledge about this cross-cutting concept within the context of this technology topic area
2. C → Capabilities, i.e., the course will develop capabilities in this cross-cutting concept that can be applied within the context of this technology topic area
3. D → Decision-making, i.e., the course will enable decision-making within the context of this cross-cutting with regards to this technology topic area

4. Blank – Indicates that this cross-cutting concept is not covered to any extent within this technology topic area

These three areas (K, C, D) are based on the three Cognitive Dimensions of Technology Literacy that are defined in *Technically Speaking* [5] and *Tech Tally* [3] where "Critical Thinking & Decision-making" has been simplified to "Decision-making". The levels (K, C, D) are ordered in terms of their depth of understanding, and it is implied that higher levels of coverage (e.g., Decision-making) also include the lower levels of understanding as well (i.e., Knowledge and Capabilities). This is consistent with the scheme used in Bloom's taxonomy where higher levels of the taxonomy include the ability to demonstrate the lower-level skills as well [69,70].

Using this 2D matrix representation, four generic types of technology literacy courses can be defined. These four types constitute the standard course models that were envisioned as part of the NSF/NAE Technological Literacy Workshop [1,2]:

(1) Technology Survey Courses
(2) Technology Focus Courses
(3) Technology Design Courses
(4) Technology Critique, Assess, Reflect, or Connect (CARC) Courses

These are shown in Figure 2. To simplify the figures, the cross-cutting concepts (i.e., the rows) have been condensed into the three higher-level groups (Systems, Design, and Connections). As shown in the figure, it is hypothesized that Survey Courses will span the majority of the matrix with K, C, and D values (see Figure 2a). Due to time constraints and limited course duration, it is not anticipated that any Survey course will fill the entire matrix, but it would be expected that no row will be entirely blank – if it is, then it will not likely qualify as a good Survey course. Meanwhile, a column could be blank if a technology topic area is not covered due to time limits, but a good Survey will likely cover most of these technology areas.

Technological Literacy Focus Courses will go into great depth within one or more technology topic areas (see Figure 2b) with a higher percentage of C and D values in that column(s) when compared to a Tech Lit Survey Course.

Technological Literacy Design Courses and Critique, Assess, Reflect, or Connect (CARC) Courses will cover these respective rows in the matrix for one or more of the technology topic areas as shown in Figures 2c and 2d, respectively. It is expected that these courses will also have a higher percentage of C and D values in the corresponding rows – specifically for the detailed cross-cutting concepts within each group – compared to a Survey Course.

Figure 3 shows two instances of the matrix for two courses that were selected from among the 22 existing technology literacy courses surveyed during the 2007 NAE/NSF Workshop [1,2]. In this survey, instructors were only asked to what extent their course covered the cross-cutting concepts at the group level (System, Design, and Connections) and which technology topic areas were covered, but not to what extent each cross-cutting concept was covered in each technology topic area. It can only be determined to an approximate extent what a Technology Survey Course (see Figure 3a) and Technology Focus Course (see Figure 3b) will actually look like; however, it provides reasonable proof-of-concept for this matrix representation. Similar instances of Technology Design Courses and Technology CARC Courses can also be found in the 22 courses surveyed for the workshop [1,2].

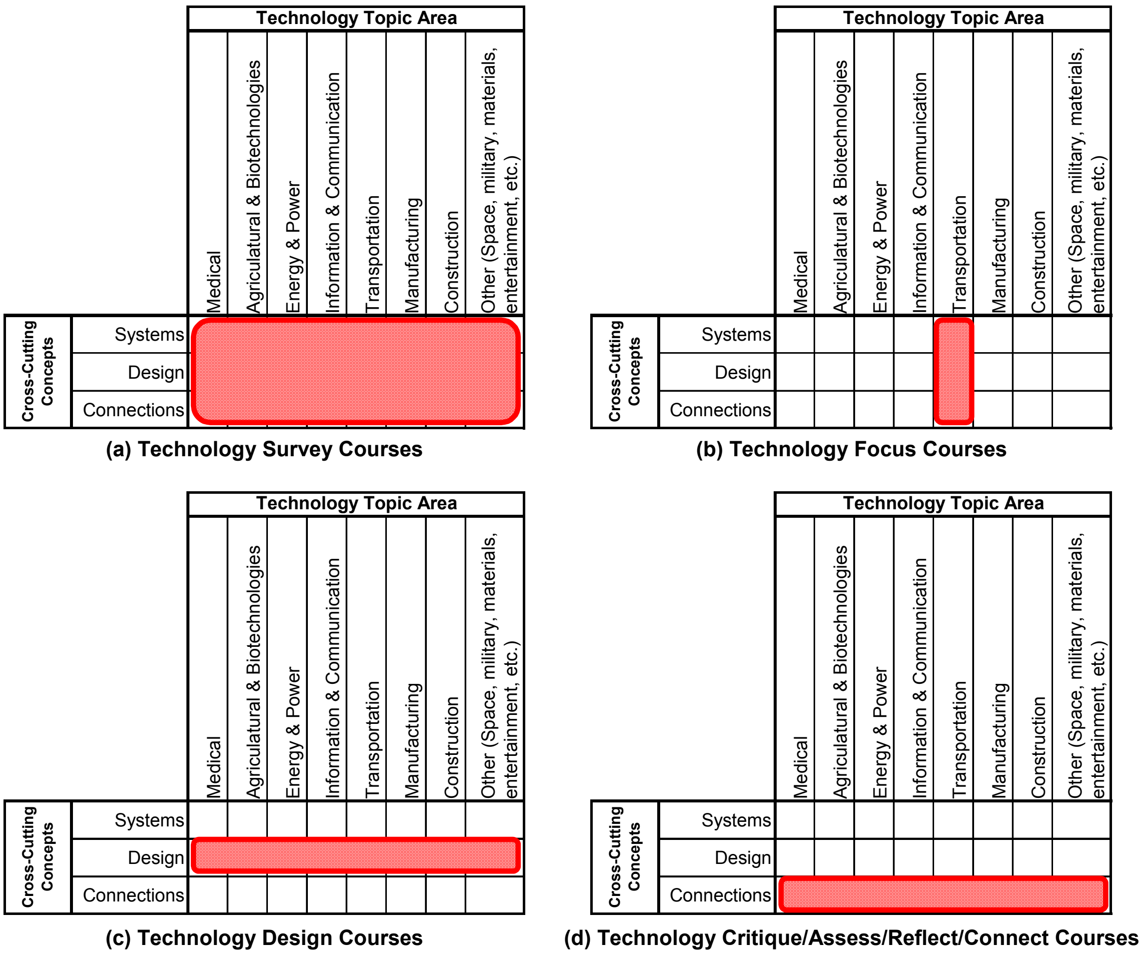
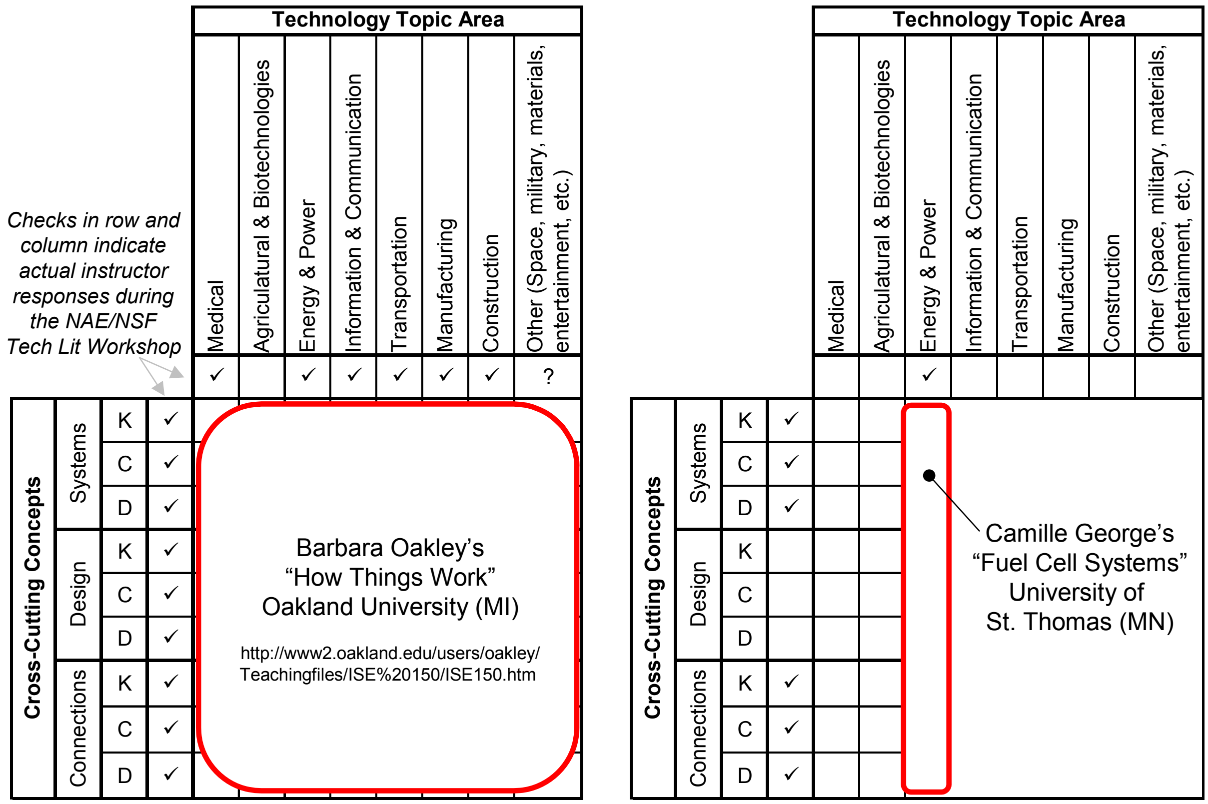


Figure 2. Using the Matrix to Define Four Types of Tech Lit Courses



(a) Example of Tech Lit Survey Course (b) Example of Tech Lit Focus Course

Figure 3. Instances of the Matrix based on 22 Tech Lit Courses at NAE/NSF Workshop

Description of Future Work

The proposed framework for evaluating technology literacy courses emerged, in part, from a survey of technology-focused courses and their instructors conducted before the NSF/NAE workshop. This online survey asked instructors to compare their existing course to the standards prescribed in *Tech Tally* [4] and the ITEA *Standards for Technological Literacy* [8]. The survey only addressed the broadest outlines of the standards and did not include any other aspects of the course such as pedagogy and assessment. The initial survey resulted in 22 courses [1,2]. Future work will broaden the data base of courses reviewed.

The framework shown in Figure 1 could serve as an organizational infrastructure for a web-based repository of shared course materials. This online matrix will link to course materials from existing technological literacy courses and allow users to build technological literacy courses by selecting materials from cells, rows, or columns as needed. Contributing educators could populate the matrix by either submitting modules or full course materials. Posting modules or courses will automatically populate one common matrix familiar to all instructors. Users will be able to view individual course matrices or explore along one dimension (row or column) of the common matrix. Each matrix cell will have a pull-down menu indicating cognitive level K, C, and D. Users will be able to select the appropriate depth and post material to, or take material from, any given depth and category. In addition to downloading modules, users will be able to build a complete course online.

The long-range goal of this work is to populate all cells of this framework with publicly available materials. These materials will then be accessed from the web and used by instructors to develop curriculum for new courses in technological literacy. The goal is to simplify the course development task for faculty members at all institutions, both two- and four-year. Providing a wiki-like environment of best-practice materials open to the public with controlled editing access will help broaden participation in this area.

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