Technological Literacy: Assessment and Measurement of Learning Gains

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America's standard of living and way of life depend upon technology. It is vital for both empowerment of the individual and national economic growth. Informed citizens should have an understanding of what technology is, how it works, how it is created, how it shapes society, and how society influences technological development. Despite the centrality of technology to our well-being, there is little research measuring the degree to which undergraduate students, out-of-school adults, and other adults outside of the K-12 setting possess a broad understanding of the principles, products, and processes of technology. While formalized measurement is lacking, a significant number of faculty members have been teaching courses on technological literacy and assessing student learning in their individual classes. The work reported here describes the initial stages of an effort to collect and refine these existing assessments used by individual faculty into standard assessment tools that can be broadly applied. These assessment tools can then be used by faculty to assess technological literacy learning outcomes. The combined results will begin to create a broadly-based characterization and measurement of the technological literacy of American undergraduates and the potential effectiveness of technological literacy courses. While assessment of learning gains within courses that form part of an engineering major have been developed under ABET EC 2000, the means of assessing the technological understanding of the majority of undergraduates who are not engineering students is yet to be systematically addressed. This work begins an effort to create some assessment tools appropriate for use with the large number of students who are not majoring in one of the STEM disciplines. Some initial results will be described on the development of these assessment tools resulting from a workshop of undergraduate STEM educators convened in July 2012.

Background

The use of advanced technology defines our modern economy and way of life. Given technology's pervasive influence and our dependence upon technology, informed citizens should possess an understanding of technology, how it is developed, how it works, how it affects society, and how society determines the path of technological developments. In *Technically Speaking: Why All Americans Need to Know More about Technology,*[1] the National Academy of Engineering (NAE) has made an effort to publicize and clarify the importance of technology in our daily lives.

Technological and engineering literacy are defined as a capacity to understand the broader technological world. Technology is defined as the many diverse products of engineering. Technology is not merely personal computers and information technology. Technology is any modification made to the natural world to meet a human need or want. Technology includes not only tangible, physical products, but also the processes and knowledge needed to operate and create these products. Also included as part of technology are the facilities and expertise needed in the design, manufacture, operation, and repair of technological devices and systems.

Assessment of Engineering and Technological Literacy

Despite the importance of engineering and technological literacy, few formal methods exist to measure or assess the broad understanding of the technological world by individuals who are not technical professionals in one of the STEM disciplines. It is the case that assessment of the learning outcomes that characterize an engineering major has been developed extensively under ABET EC 2000. However the means of assessing the technological understanding of the majority of undergraduates who are not engineering students is yet to be systematically addressed.

An examination of existing methods for measuring technological and engineering literacy was carried out by the NAE Committee on Assessing Technological Literacy and published as *Tech Tally* in 2006.[2] The committee considered a wide range of non-engineers including assessing technological literacy of K-12 students and teachers and determining the technological understanding of adults who are no longer in school. The NAE committee reached several conclusions in the course of its review. The consensus was that very little work had been done to measure the broader understanding of technology among the general population and no appropriate, broadly-based assessment instrument yet exists. Some observations made by the NAE Committee on Assessing Technological Literacy are included in Table 1.

Table 1: Observations by the NAE Committee on Assessing Technological Literacy.

> *"Thus far, no studies have addressed general engineering concepts, such as systems, boundaries, constraints, trade-offs, goal setting, estimation, and safety."*
>
> *"Not a single study investigates what the general public understands about these concepts, much less how they come to understand them."*
>
> *"the assessment of technological literacy [is] in its infancy."*
>
> *"no single [existing] instrument struck the committee as completely adequate to the task of assessing technological literacy."*

Framework for Assessing Engineering and Technological Literacy

As part of the work for *Tech Tally*, the NAE Committee on Assessing Technological Literacy also developed a working definition of technological and engineering literacy. Technological literacy is defined in terms of specific content areas and depth of knowledge. The committee started from the three dimensions of technology described in *Technically Speaking* and considered these to be three cognitive levels relevant for assessment. The term "Ways of Thinking and Acting," was rephrased to "Critical Thinking and Decision Making." Four content areas of technological knowledge were defined. These are: technology and society; design; products and systems; and characteristics, concepts, and connections. The NAE view of

technological literacy as a combination of content and depth of knowledge, or cognitive dimension, is summarized in Figure 1, which is derived from Figure ES-2 from *Tech Tally*.

COGNITIVE DIMENSIONS

	Knowledge	Capabilities	Critical Thinking & Decision Making
Technology & Society			
Design			
Products & Systems			
Characteristics, Core Concepts, & Connections			

CONTENT AREAS (vertical label on left)

Figure 1: Content Areas of Technological and Engineering Literacy as Described in *Tech Tally*.

While the NAE Committee on Assessing Technological Literacy found that no generally suitable assessment instruments existed, it identified two opportunities. These were the modification of existing assessments; and the development of new assessments. The Committee observed that suitable tools to assess technological literacy might be created by adapting or modifying existing assessment tools. As stated in *Tech Tally: "This plug and- play approach would also provide data about technological literacy relatively quickly."*[2] The approach of the workshop reported here pursued the path of modification existing assessments.

Overview of Workshop Methods

This work seeks to develop assessment tools based on existing course assessments already used by faculty. The approach taken is based on the assumption that suitable assessments of technological and engineering literacy might be developed through modification or adaptation of existing course assessments. The starting points for broadly applicable assessment tools may already exist in the assignments, tests, quizzes, and projects that faculty have already developed.

Faculty members who are already teaching courses on technological literacy are already carrying out some types of assessments in these classes. It is likely that these assessments may not be suitable for broad application and publishable results. However, with modification, these course assessments may be suitable as standard assessment tools for the technological literacy of undergraduates. For the sake of efficiency, it seems advisable to attempt to follow the

recommendation made by the NAE Committee on Assessing Technological Literacy in *Tech Tally* that suitable assessment tools and relatively quick results might be obtained by adapting or modifying existing assessment tools. It also notable that in *How People Learn*, Bransford, et al. mention the importance of not overlooking the potential of successful, but empirically-developed, materials and techniques.[3]

A significant number of the members of the Technological Literacy Division of ASEE teach technological literacy courses for undergraduate students. It is not unreasonable to expect that that there are dozens of potentially suitable assessment questions already in use in undergraduate technological and engineering literacy courses. Because the scholarly community devoted to this topic is only recently formalized, much of the work done by these faculty members has not been published or is in an unrefined state.

A two-day workshop was held in July 2012 for the purpose of beginning the process of developing a broadly-applicable assessment tool to measure engineering and technological literacy. The workshop was attended by 25 individuals, most of whom were faculty members teaching engineering and technological literacy courses for undergraduates. An effort was made to achieve a distribution of institutions represented by the participants. Institution types included two-year colleges, primarily undergraduate institutions, comprehensive regional universities, and research universities. The distribution of institutions represented is shown in Table 2. The workshop participants contributing to the development of assessment methods reported here are listed in Table 3.

Table 2: Distribution of Workshop Participants Institutions Types.

Institution Type	Representation
Two-Year Colleges	20 percent
Primarily Undergraduate	16 percent
Comprehensive / Regional Universities	44 percent
Research Universities	20 percent

Outline of Approach Developed for Engineering and Technological Assessment

In the course of the workshop activities, the contributors agreed on a general format or approach that the technological and engineering assessment would take. Technology and engineering are exceptionally broad topics and a diversity of opinion exists as to the appropriate subdivisions and categories around which an assessment might be structured. It was decided to use the content areas divisions that were developed by the NAE Committee on Assessing Technological Literacy. These content areas are listed in Table 4. These NAE contents areas are also consistent with those used in the K-12 sector for the development of a Technology and Engineering Literacy Assessment as part of the National Assessment of Educational Progress (NAEP). This is a US Department of Education effort associated with America's report card.[4,5]

Table 3: List of Workshop Participants Contributing to Assessment Development.

Workshop Participant	Institution
Tish Allen	Appalachian State University
John Blake	Austin Peavy State University
Dan G. Dimitriu	San Antonio College
Kate Disney	Mission College
Linda Dake	Utica College
Maria T. Earle	Mississippi State University
Bill Graff	LeTourneau University
Carl Hilgarth	Shawnee State University
John Krupczak	Hope College
Douglass Klein	Union College
William Loendorf	Jones International University
Mani Mina	Iowa State University
Steve Macho	Buffalo State University
Steve O'Brien	The College of New Jersey
Paul Post	Ohio State University
Polly Pergiovanni	Lafayette College
JoAnn Panzardi	Cabrillo College
Cathy Ringstaff	WestEd
Mary Annette Rose	Ball State University
Liz Rozell	Bakersfield College
Carolyn Sealfon	Princeton University
Mariana Tafur	Purdue University
Peter Trajan	University of Miami
Steve Walk	Old Dominion University
Jim Young	Rice University

Table 4: Engineering and Technological Literacy Content Areas.

1.)	Technology & Society
2.)	Design
3.)	Products & Systems
4.)	Characteristics, Core Concepts, & Connections

The engineering and technological literacy content areas are intended to encompass the wide array of topics that define an understanding of the broader technological world. It should be noted that the boundaries between the content areas are indistinct and some overlap of topics might exist across content areas. "Technology and Society" concerns the relations between humans and technology. This includes issues such as ethics and responsibility and the history and evolution of technology. The "Design" section focuses on the methods though which engineers create new technological products and systems. Content would include design methodologies, cost-benefit analysis, and design evaluation. "Products and Systems" addresses

the systems nature of technology, and includes topics such as the flow of energy, materials, and information in systems, feedback and control, and the specific technologies characterizing modern society. The "Characteristics and Core Concepts and Connections" area comprises topics such as the nature of technology, the scientific principles incorporated in technology, and content from other disciplines relevant to engineering and technology. These other disciplines might include, but are not limited to, the various disciplines of science and mathematics.

It was decided in the workshop that the technological and engineering literacy assessment test would be most useful if it had characteristics similar to a concept inventory. The most well-known example of this assessment approach is the Force Concept Inventory as developed by Hestenes, Wells, Swackhammer, and others[6]. A list of features of concept inventories are summarized in Table 5. Key features of concept inventory tests are the use of a multiple-choice question format, and inclusion of a variety of distractor options to help reveal the nature and extent of misconceptions. Concept inventories avoid questions that can be answered using common sense or simple calculation skills. It was felt that the length of the Force Concept Inventory was an appropriate guideline for the order of magnitude length of the possible sections of a technological and engineering literacy assessment. The Force Concept Inventory is 30 questions.

Table 5: Summary of Concept Inventory Characteristics.

Multiple choice format for questions.
Require substantial understanding of concepts
Not simple calculation skills
Not common sense
Include a variety of distractors
Reveal extent and nature of misconceptions
The same test is taken pre and post

The group also determined that the assessment instrument would be most useful if the questions addressing capabilities and critical thinking could be self-contained and not mix the knowledge of specific facts with the ability to complete critical thinking tasks. Examples of assessments with these features include the Miller Analogies Test[7], the Law School Admissions Test[8], and the ACT Science Reasoning Test[9]. In each case the factual information needed to engage in the higher level cognitive tasks is included in the question.

Results to Date and Samples of Draft Questions

Activities at the workshop centered around work in three groups. Each group had eight members. The groups met in several sessions to review the existing course assessments contributed by participants and to draft parts of potential assessment instruments. The groups reported back to each other at several intervals. Because of the wide-ranging discussion and flow

of ideas and suggestions, the initial results reported here represent the aggregate contributions of all the individual participants listed in Table 3.

Samples of drafts of potential technological and engineering literacy questions are listed below. The questions are grouped under the four technological content areas of Technology and Society, Design, Products and Systems, and Core Concepts. These questions are intended to provide examples of the types of questions that could be included in an assessment of engineering and technological literacy that is generally applicable for use with undergraduates who are not studying engineering. As in the case of the Force Concept Inventory, it would not be advisable to include the entire assessment in a publication which might be accessible to the students being evaluated.

Sample Draft Questions

TECHNOLOGY and SOCIETY
1.) Government has had a persistent role in technology development because
    A. Corruption of government officials disrupts or controls technology development.
    B. Government can be a very effective way to carry out collective will.
    C. Technology requires government intervention to progress.
    D. Private business and individual inventors act in self-interest without regard for social progress.

2.) Which of the following important historical events conceivably would not have occurred without significant contributing technological factors?
    A. The success of early agriculture-based, stable societies.
    B. The rapid expansion of the US across the North American continent in the 1800s.
    C. The elimination of polio as a major childhood illness in the mid-20th century.
    D. All of the above.

3.) Changes in energy policy to reduce the production of carbon dioxide production in the United States …
    A. Can be made by the federal Environmental Protection Agency.
    B. Can be effectively made by individual states with each state potentially having different standards.
    C. Can be made by the federal government in a process that is influenced by different interests and is likely to be a compromise between competing interests.
    D. Can be done by each individual citizen; no collective effort is needed.

DESIGN

4.) A team is trying to design a robot that will shoot balls through a hoop, and has come up with four solutions. How should they decide which one to try first?

    A. Vote.
    B. Ask their instructor.
    C. Let the team leader choose.
    D. Rank solutions using design criteria.

5.) Students in a solar car design challenge have just tested the aerodynamic drag of their third design for the housing of their car. Testing indicates a decrease in overall drag. Students in this solar car design are demonstrating:

    A. an iteration in a step of the design process in order to improve their solution.
    B. the ability to list multiple solutions to the problem.
    C. rank order criteria by importance.
    D. their ability to evaluate the environmental impact of their solution.

PRODUCTS AND SYSTEMS

6.) Which of these technological systems requires energy to operate?

            (a) Bicycle
            (b) Commercial Jet Airplane
            (c) Automobile

    A. a only
    B. b only
    C. c only
    D. b and c
    E. a, b, and c

7.) Which of the following best explains why technological systems such as an automobile are composed of parts or components?

    A. The individual components help the system to operate by fulfilling some portion of the system operation.
    B. Components are used to reduce the cost of the system by reducing the amount of material used.
    C. Using components improves the reliability of the system by combining several functions into a single unit.
    D. Using components improves the reliability of the system by dispersing several functions among many independent elements.

CORE CONCEPTS
8.) What happens to the energy used to operate a toaster after the toaster is finished toasting?
    A. It still exists in the toast and toaster, around the toaster, and in the air.
    B. It returns to the electric company.
    C. It is consumed by the toast.
    D. It gradually disappears until none of it remains anywhere.

9.) You belong to a company that gives all employees identical thumb drives. You leave your thumb drive on a table along with several other drives. Now you are unsure which drive is yours. What do you do?
    A. To determine the owner of the drive it is safe to insert the drive in your laptop and look for contact information.
    B. In order to determine the owner of the drive it is safe to insert the drive in the office computer and look for contact information.
    C. You're better off using a non-networked isolated computer to look for owner contact information.
    D. Turn into company security, do not insert on any computer.
    E. Only a, b, and d.
    F. Only d.

These questions provide a sample of the types of knowledge, capabilities, and critical-thinking skills that would characterize an individual who has a broad understanding of technology. All of these questions were developed as part of the deliberations between the workshop participants.

Conclusions and Future Work

The goal of creating a general and broadly applicable assessment of engineering and technological literacy is a challenging task but one that may be efficiently addressed by making use of the diverse experiences of faculty who have been teaching engineering and technological literacy courses for non-engineers. The work reported here shows that a group of engineering faculty and other experienced educators were able to integrate some elements of existing course assessments into draft questions that begin to characterize and measure engineering and technological literacy. The project work is ongoing. Two current goals are soliciting input from other educators and STEM professionals interested in this topic, and completing a full-length assessment for pilot testing.

Acknowledgement

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