The Development of Technology/Engineering Concepts in Massachusetts Academic Standards

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Over the past decade Massachusetts has developed academic technology/engineering standards and implemented related programs. This work has been a reference point for a number of other states and countries looking to support engineering education. This paper outlines the process Massachusetts has undertaken and some of the successes and challenges related to the implementation of engineering concepts.[1]

The development of state technology/engineering standards was initially made possible through the Massachusetts' 1993 Education Reform law but was only carried out through the advocacy of technology education educators and engineers with an interest in education. Massachusetts treats technology/engineering as a discipline within science, equivalent to physical science, life science, and earth and space science. A number of state policies support the implementation of school and district technology/engineering programs aligned with the standards, such as licensure and assessment expectations. A number of challenges remain, however, before technology/engineering can be considered to have developed to a point equivalent to the traditional science disciplines.

Roots of technology/engineering in Massachusetts

The development of technology/engineering standards in Massachusetts started with the inclusion of language in the 1993 Massachusetts Education Reform Law:

> The board shall…develop *academic standards* for the core subjects of mathematics, *science and technology*, history and social science, English, foreign languages and the arts. … The board may also include in the standards a fundamental knowledge of *technology education* and computer science and keyboarding skills… (Massachusetts General Laws, Chapter 69, Section 1D, italics added)

The inclusion of "science and technology" in this legislation formed the impetus for the development of the first state *MA Science and Technology Curriculum Framework* (MA ESE, 1996). The inclusion of the word technology in this label sparked state-wide discussion of what that should include. For the science education community, it was indicative of a science, technology, and society (STS) perspective reflective of *Science for All Americans* (AAAS, 1989) and the *National Science Education Standards* (NRC, 1996). For the technology education community, it was indicative of a technological literacy perspective reflective of *Technology for All Americans* (ITEA, 1996). There was some discussion as to whether it meant computers—instructional technology—but the inclusion of the label "technology education" in the later statement about what the board "may also include" was interpreted as the reference to this. The final result of the state-wide discussion was an initial (1996) state framework that defined "science and technology" as an academic subject that integrated STS and technology education perspectives. Later, in the 2001 framework revision (MA ESE, 2001), the STS perspective was reduced and replaced with more specific engineering principles, leading to the modified framework title "science and technology/engineering."

The vision of technology/engineering

This paper is not the place to outline the reasons technology/engineering education adds significant value to student learning and our educational programs. Those rationales are well developed elsewhere. It is worth, however, explaining the general motivations of those advocating for technology/engineering in Massachusetts during each framework process.

During the development of the initial 1996 framework, technology education staff promoted the need for students to develop technological literacy in addition to scientific literacy. They also strongly argued that technology education courses promoted hands-on opportunities for students, particularly a certain population of students who were not succeeding in 'traditional' science courses. These arguments articulated the educational value of the discipline. A third argument involved the adults: having the topics of technology education represented in a core academic framework would justify their jobs. It was their contention that administrators would find it harder to eliminate technology education programs if those programs directly contribute to student learning of a core academic discipline.

In the revision process leading to the 2001 framework, engineers with an interest in education entered the state conversation to advocate for expanding the technology element of the framework to include engineering principles. These engineers advocated for the need for standards to promote engaging, innovative programs to interest students in current methods and issues of design and support the state's need for engineers and technicians.

The academic framework over time

Basic structure

The state science standards follow a consistent format: strands (disciplines) contain a number of core topics that are specified through standards. There are five strands in the current MA framework: Earth and Space Science, Life Science (Biology at high school), Physical Science (splits to Chemistry and Introductory Physics at high school), and Technology/Engineering. Each are treated equally in state policies, such as course credit for graduation, licensure, and state testing. Each strand is made up of 6-9 topics; each topic has between 2 and 10 standards.

Influential reference documents

The development of the initial *1996 MA Science and Technology Curriculum Framework* drew upon the nation's seminal standards documents for science education, including the *National Science Education Standards* (NRC, 1996) and the *Benchmarks for Scientific Literacy* (AAAS, 1993), as well as the *1996 NAEP Science F*ramework (USED, 1996). For the *2001 MA Science and Technology/Engineering Curriculum Framework*, the NRC and AAAS documents were once again used as reference with the *2000 NAEP Science Framework* (USED, 2000) and *Standards for Technological Literacy* (ITEA, 2000) added as core references. In addition, policy factors the led to the articulation of the 2001 No Child Left Behind Act (NCLB) were considered; in particular the expectations of content as a central focus and standardized assessments.

For the expected 2011 revision of the framework, the seminal science and technology education documents are again being used as references, substituting the *2009 NAEP Science Framework* (USED, 2008), and adding references being developed by Achieve, Inc. which will analyze international benchmarks.

1996 Framework technology topics and sample standards
With references and advocacy from both the science and technology education communities, the technology topics found in the initial 1996 framework reflect the combined STS and technology education perspectives:

1996 Technology topics (high school)
- The design process
- The nature and impact of technology
- Technology yesterday, today and tomorrow
- The tools and machines of technology
- Resources of technology
- Technological areas of communication, construction, manufacturing, transportation, power, and bio-related technologies

Figure 1. High school technology topics in the *1996 MA Science and Technology Curriculum Framework*.

These combined perspectives are also found in the specific standards:

Resources of Technology
* Identify particular characteristics of material resources, i.e., synthetic, composite, and biological. Explain how various energy sources and forms of information are also resources with specific characteristics.
* Discuss issues of resource management including safety, costs, environmental and political concerns. Discuss a current example such as waste management and nuclear power systems.

Technological areas of communication, construction, manufacturing, transportation, power, and bio-related technologies
* Give examples of how combinations of graphic and electronic communication processes are used in developing high technology communication systems.
* Describe uses of material conversion processes, i.e., separating, forming, conditioning and combining, in production processes.
* Identify ways that manufacturing processes have changed with improved tools and techniques.
* Compare how existing transportation technologies convey people and products globally.
* Give examples of ways in which technological processes could adversely affect the environment. Choose a current example from your local news to investigate.

Figure 2. Sample 1996 standards from two technology topics.

2001 Framework technology/engineering topics and sample standards
With the advocacy of engineers with an interest in education, a number of changes were made to the technology topics and standards in the framework. In particular, technological design was modified to become the engineering design process; additional topics for energy and power systems were added, and the social implications of technology were removed. The technology/engineering topics found in the 2001 framework reflect the combined technology education and engineering perspectives:

2001 Technology/Engineering topics (high school)

- Engineering design
- Materials, tools, and machines
- Communication technologies
- Manufacturing technologies
- Construction technologies
- Transportation technologies
- Energy and power systems—fluid systems
- Energy and power systems—thermal systems
- Energy and power systems—electrical systems
- Bioengineering technologies

Figure 3. High school technology/engineering topics in the *2001 MA Science and Technology/Engineering Curriculum Framework*.

These perspectives are also reflected in the specific standards:

2. Construction Technologies
Central Concepts: The construction process is a series of actions taken to build a structure, including preparing a site, setting a foundation, erecting a structure, installing utilities, and finishing a site. Various materials, processes, and systems are used to build structures. Students should demonstrate and apply the concepts of construction technology through building and constructing either full-size models or scale models using various materials commonly used in construction. Students should demonstrate the ability to use the engineering design process to solve a problem or meet a challenge in construction technology.

2.1 Identify and explain the engineering properties of materials used in structures (e.g., elasticity, plasticity, R value, density, strength).
2.2 Distinguish among tension, compression, shear, and torsion, and explain how they relate to the selection of materials in structures.
2.3 Explain Bernoulli's principle and its effect on structures such as buildings and bridges.
2.4 Calculate the resultant force(s) for a combination of live loads and dead loads.
2.5 Identify and demonstrate the safe and proper use of common hand tools, power tools, and measurement devices used in construction.
2.6 Recognize the purposes of zoning laws and building codes in the design and use of structures.

3. Energy and Power Technologies—Fluid Systems
Central Concepts: Fluid systems are made up of liquids or gases and allow force to be transferred from one location to another. They can also provide water, gas, and/or oil, and/or remove waste. They can be

moving or stationary and have associated pressures and velocities. Students should demonstrate the ability to use the engineering design process to solve a problem or meet a challenge in a fluid system.

3.1 Explain the basic differences between open fluid systems (e.g., irrigation, forced hot air system, air compressors) and closed fluid systems (e.g., forced hot water system, hydraulic brakes).

3.2 Explain the differences and similarities between hydraulic and pneumatic systems, and explain how each relates to manufacturing and transportation systems.

3.3 Calculate and describe the ability of a hydraulic system to multiply distance, multiply force, and effect directional change.

3.4 Recognize that the velocity of a liquid moving in a pipe varies inversely with changes in the cross-sectional area of the pipe.

3.5 Identify and explain sources of resistance (e.g., 45º elbow, 90º elbow, changes in diameter) for water moving through a pipe.

Figure 4. Sample 2001 central concepts and standards from two technology/engineering topics.

Emergence of academic technology/engineering in Massachusetts

The articulation of technology/engineering standards into the core academic framework, initially led by the state technology education organization, was a first step to incorporate these concepts into the educational system. In the early- to mid-1990s, industrial arts made a shift to technology education. These technology education programs (of which many still exist in the state) are generally characterized as elective, supplementary programs that focus primarily on the development of student skills and products, but not as much on trade skills and tool use as industrial arts had emphasized. The new discussion about becoming a core academic discipline pushed technology education to consider the implications of yet another shift: moving away from a supplemental, technical-oriented technology education program toward an academic, knowledge-oriented technology/engineering program. This took them even farther from their long and productive history of skills development and tool use. While individual teachers made progress in making this transition, creating an initial set of technology/engineering courses in the process, the overall field of technology education has struggled with this second shift.

The implications of this second shift continue to pose one of the most significant challenges related to the systematic implementation of technology/engineering standards in Massachusetts. Many technology education staff did not want to make yet another shift. This split the state’s technology education organization into two: one aligned more to the industrial arts--technology education perspective and the other aligned to the technology/engineering--academic perspective. Others who were watching this process, including school and district science staff, curriculum coordinators, and administrators, took this as one reason to delay the incorporation of technology/engineering concepts into school programs. Between 1996 and the mid-2000s science staff and organizations generally did not take ownership of technology/engineering standards; they viewed technology/engineering as the responsibility of technology education teachers. Another reason, not associated with the organizational events but related to the recent shift away from industrial arts, was that educational staff and parents were slow to change their conception of past technical-oriented programs to embrace the possibility of an academic technology/engineering program.

Only recently have more schools and districts begun to transition technology education programs into their science departments. Those that have are often merging these two departments into a “science and technology/engineering department.” This is due, in part, to several developments. First, the MA Department of Elementary and Secondary Education (Department) has worked over the years to align all state policies so that technology/engineering is treated the same as all other science disciplines. This provides schools and districts the support they need to develop academic technology/engineering programs. Relationships between the two technology education organizations are starting to heal. And finally, the Boston Museum of Science, with its associated National Center for Technological Literacy, has become an active leader in promoting technology/engineering. These developments were significant as they moved the discipline away from the tensions of organizational strife and associations with past technical programs. The Museum’s development of technology/engineering curriculum provided administrators, science staff, and parents an image of what technology/engineering curriculum could look like. It also showed how technology/engineering concepts related to more traditional science concepts. Along with education of administrators and guidance staff, the curriculum has had a significant impact in the establishment of technology/engineering programs across the state.[2]

Development of Department policies

Policy successes

While taking years to complete, significant progress has been made by the Department to align the various policy elements so that technology/engineering is treated as an academic discipline. The grounding in the state’s 1993 Education Reform law was key in making this possible; just as it formed the basis to develop the standards, it also provides the justification for corresponding policies. The Department has also argued that the structure of technology/engineering and traditional sciences is similar. Both articulate a core body of knowledge and both have an articulated process (closely aligned to each other) to guide practice and generate new knowledge. These are, in effect, equivalent, allowing us to claim (from a policy perspective) that technology/engineering can be counted *as a science*. These provide the rationales for changes to all other policy elements.

Once the first framework was developed, the state’s science assessment followed. Since technology/engineering is a strand in the framework, equivalent to the other science disciplines, the Massachusetts Comprehensive Assessment System (MCAS) incorporated technology/engineering items. Technology/engineering is currently 15% of the grade 5 test, 25% of the grade 8 test, and one of the four options for the high school end-of-course test.

Next, the licensure expectations for teachers of technology/engineering had to be adjusted. This took much longer to implement. The Department currently offers an academic license titled “technology/engineering” which has equivalent expectations as any other science license: required content knowledge expectations (including passing a content test), completion of a practicum, licenses available for grade spans PreK-8 and 5-12, and being “highly qualified” as required by NCLB. Since, however, this subject developed through the progression of industrial arts to technology education to technology/engineering, the license was not completely new; it is actually a transition of the corresponding licenses of the same titles. So all industrial arts and technology education certified teachers are grandfathered into the system: they hold an appropriate license to teach a core academic technology/engineering course. While this provided a pool of teachers qualified to teach the new subject, it led to reasonable questions by administrators about whether those teachers were really qualified to teach the new subject.

Finally, since the state recognizes technology/engineering as a core academic science option, schools and districts can give science credit for these courses and apply those to high school graduation requirements. The alignment of all these policies means that schools and districts have support they need to develop academic technology/engineering programs.

Policy challenge
One significant policy challenge remains for the state: alignment of high school graduation expectations and state college admission requirements. This issue has only recently come to be a focus: for one reason, it took the implementation of enough technology/engineering programs to provide a significant number of students with these credits, and secondly, addressing it requires alignment between the Department, the Massachusetts Department of Higher Education, and, interestingly, the National Collegiate Athletic Association (NCAA).

While the Department allows for schools to apply technology/engineering courses to science graduation requirements, the Department of Higher Education does not yet recognize those courses as "natural/physical science" courses for admission purposes. Since most higher education institutions have separate science and engineering departments these disciplines are not necessarily viewed as being equivalent. Added to that, the higher education institutions have not had a chance to learn about the nature or rigor of the high school technology/engineering courses. When they conduct a transcript review for purposes of student admission, technology/engineering courses are not being counted as fulfilling science requirements. This issue is actively being discussed and will hopefully be resolved before long.

The alignment to NCAA is bit more abstract but just as important. NCAA does its own transcript review of any student who wants to play or receive a sports scholarship at an NCAA-affiliated institution. To carry this out, NCAA pre-approves all high school academic courses through a syllabus review, submitted to NCAA by high school guidance departments. When MA high schools submitted technology/engineering courses for review as science courses, NCAA was rejecting them on the rationale that they were "vocational" rather than academic courses, no matter what the school provided for evidence. And once the rejection letter was received, the guidance department would then tell the science and/or technology education department that the course could not be added to the school's program of studies for science credit. To address this, the Department wrote to NCAA explaining how the state incorporates technology/engineering into science as an academic subject, and asked that any future requests be reviewed as such. NCAA agreed to do so and has begun to approve these courses.

School, district, and higher education implementation
Implementation successes
Schools and districts have implemented a range of K-12 curriculum aligned to technology/engineering standards. While the Department has not collected unit lessons or syllabi, evidence of successful implementation is seen in the inquiries made by schools to the Department about implementation issues and curriculum development, newspaper articles about technology/engineering offerings, and students taking the high school technology/engineering MCAS test. The Department has also seen more district administrators taking an interest in technology/engineering, particularly those who follow state economic policy discussions where

biotechnology and high-tech themes have been ongoing for several years now. Finally, the development of published curricula (primarily the Museum of Science) and textbooks (such as by publishers Glencoe, Goodheart-Wilcox, and Great Lakes Press) aligned to state standards have made it easier to start programs.

Local successes have also been seen in the recruitment of career changers to the teaching force. Districts are reporting success in hiring ex-engineers who have chosen to enter teaching and engage in the development and teaching of technology/engineering programs. These staff bring real-world experience to their instruction and a perspective that values the integration of traditional science topics with technology/engineering topics.

There have also been changes at an organizational level. A number of high schools have merged their science department and technology education department to create a "Science and Technology/Engineering Department." The state's technology education professional organizations are now explicitly including engineering in their missions and titles. The state's science fair organization also changed its name in 2006 to the *Massachusetts State Science and Engineering Fair* and expanded the types of projects that are submitted and judged.

Implementation challenges

Schools and districts have the justification to implement technology/engineering programs through state policies. There are, however, a number of implementation challenges they must still navigate. Distinguishing between technical and academic offerings is one challenge; local history and experience sometimes makes transitioning technical programs to an academic focus difficult. As schools look around the state for examples and models, they are confronted by a wide range and varied quality of programs and courses. Many programs were initially created by individuals and so vary widely in design. And until the science and technology education staff and organizations begin to collaborate in more specific ways it is unclear as to who teachers and schools approach for support when they want to develop a program.

Once a program is established, another implementation issue schools confront is a limited supply of certified teachers and teacher preparation programs. There is currently only one active teacher preparation program in the state, graduating on average less than 5 new technology/engineering teachers per year. The Department is actively working to increase the number of preparation programs offering support for initial technology/engineering licenses but this takes time. Central to this challenge is that preparation programs are hesitant to invest in program development until there is a demand for teachers, but the demand is not created, in part, due to the limited number of available teachers to design and implement K-12 programs.

Lessons learned

The development of technology/engineering in Massachusetts provides a number of insights for others who may want to engage in similar efforts. The five lessons outlined below are the perspective of the author and emerge from the particular context of Massachusetts:

- Determine how the subject will be classified early—all policy decisions are based on that decision. For example, will engineering concepts be incorporated into a core academic subject, such as science, treated as an elective subject, or defined as a vocational discipline? Or some combination of these options?

- If incorporating engineering concepts into core academic science, determine whether engineering will be a subject/strand on its own (as MA has done) or as a topic in other subjects/strands (some states have a "technological design" topic within each science subject). This decision leads to other policy implications such as licensure and assessment.
- Determine the focus of the standards early. Will they just include engineering concepts, technology education concepts (ITEA, 2000), or a combination?
- Provide examples of what these courses/curriculum look like and monitor for quality and alignment. There are now a number of resources available for schools to review.
- Focus on relationships. Mediate the tension between maintaining a "technology/engineering" identity and being folded into "science." Mediate the tension between "technologists" (technology education) and "engineers." Encourage interactions of technology/engineering and science organizations early so all take ownership.

Summary

The articulation of technology/engineering standards, the implementation of policies to support those, and programs to implement them is an important endeavor for Massachusetts. Students have the opportunity to participate in relevant, engaging, and what we see as necessary programs of study. We believe this will ultimately impact our need for technologically literate citizens and a technical and engineering workforce. Elements across the entire educational system have changed to support the implementation of technology/engineering standards, although change continues to be somewhat sporadic. The articulation of the technology/engineering standards, as part of science, was the first crucial step in making all this possible. The efforts of professional organizations were crucial in making change happen, although closer attention to organizational relationships over the past 10 years could have been more productive. As the first state to include engineering concepts in state academic standards, Massachusetts has worked diligently since 1993 to overcome a number of policy and implementation challenges. Hopefully this case study will help similar efforts in other states. The development of technology/engineering resources and programs is much more likely when many states are working toward a similar goal.

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[1] This paper focuses on academic standards and programs. The state also has Career/Vocational Technical Education (CVTE) frameworks with engineering foci, including Engineering Technology, Biotechnology, Robotics and Automation Technology, among others. While fairly new (2007), there are a growing number of these programs in voc tech schools across the state. The CVTE frameworks can be found at: http://www.doe.mass.edu/cte/frameworks/

[2] The National Center for Technological Literacy (NCTL) at the Boston Museum of Science has trained over 750 teachers in the Engineering is Elementary (EiE) curriculum across Massachusetts, where approximately 115 elementary schools are now using EiE. Approximately 60 high schools have purchased the Engineering the Future (EtF) curriculum. Many high school teachers have participated in training for the EtF curriculum as well (numbers are not currently available). In addition, NCTL has supported leadership teams in approximately 55 Massachusetts districts, including over 250 teachers and administrators, to design and implement technology/engineering programs.