Standards: Mathematics and Science Compared To Technological Literacy

By Franzie L. Loepp

Standards for Technological Literacy: Content for the Study of Technology was released in April 2000 by the International Technology Education Association (ITEA, 2000). This was the first attempt by the ITEA to set forth comprehensive specifications regarding what students should know and be able to do within each of four grade bands from kindergarten through 12th grade. The purpose of this article is to compare the technological literacy standards with those that have been developed for preK–2 in mathematics (National Council of Teachers of Mathematics [NCTM], 2000) and K–12 in science (National Research Council [NRC], 1996).

Developmental Process

In some ways the development of standards in the three disciplines was similar. The main reason is that other disciplines appear to have used components of the developmental process used by the NCTM. All three disciplines relied heavily on working groups to develop draft standards. They sought input from teachers, teacher educators, and professionals in their respective disciplines. Drafts of the documents were reviewed by large numbers of practitioners, and their input was used to make revisions (Dugger, 2001). By its very nature the developmental process became somewhat political. For example, Dr. John Dossey1 said that while the majority of the leaders in the discipline favored a stronger emphasis on content in statistics, probability, and discrete mathematics, others feared inclusion of new content would detract from traditional mathematics. In the development of science standards, leaders in the subdisciplines of biology, chemistry, physics, and geology were not convinced that a single set of standards could possibly give their area of study adequate coverage.2 In technology, persons from the discipline tended to want a long list (200+) of rather specific standards, whereas the advisory committee, made up of professionals from other disciplines, particularly science and engineering, strongly advised a shorter, more manageable number.3 Nevertheless, each discipline's professional organization did publish a set of standards. Short descriptions of the processes used to develop content standards are provided below.

Technology Education

The development of the standards for technological literacy actually began in 1994 when the Technology for All Americans Project (TfAAP) funded by the National Science Foundation and NASA began to develop a *Rationale and Structure for the Study of Technology* (TfAAP, 1996). Based on this document, additional funding was received to write standards for technology education. A "standards team" made up of three groups (one for grades K–2 and 3–5; one for 6–8; and one for 9–12) was formed to write content standards. The standards team was mostly made up of technology education teachers plus a few administrators and teacher educators. These groups met periodically from 1996 through 1999, writing six drafts of the standards. The TfAAP staff refined each draft and conducted many regional reviews along with electronic reviews. A special advisory group consisting of leaders in technology education, engineering, mathematics, and science reviewed draft documents and provided valuable feedback. The NRC's standards review committee, the National Academy of Engineering special review committee, a National Academy of Engineering focus group, The National Commission for Technology for Education and elementary, middle, and high school field test sites, and hundreds of technology education teachers reviewed drafts of the document. A professional writer was hired to write the finished document that was published. See Table 1 for a listing of the Standards for Technological Literacy (ITEA, 2000). The leaders of the TfAAP are to be commended for managing this complex process (ITEA, 2000).

Mathematics

In 1986, the board of directors of the NCTM established the commission on standards

Table 1. Standards for Technological Literacy

Nature of Technology

1. The characteristics and scope of technology
2. The core concepts of technology
3. The relationships among technologies and the connections between technology and other fields.

Technology and Society

4. The cultural, social, economic, and political effects of technology
5. The effects of technology on the environment
6. The role of society in the development and use of technology
7. The influence of technology on history

Design

8. The attributes of design
9. Engineering design
10. The role of trouble-shooting, research and development, invention and innovation, and experimentation and problem solving

Abilities for a Technological World

11. Apply the design process
12. Use and maintain technological products and systems

The Designed World

14. Medical technologies
15. Agricultural and related bio-technologies
16. Energy and power technologies
17. Information and communication technologies
18. Transportation technologies
19. Manufacturing technologies
20. Construction technologies

Source: ITEA, 2000, pp. 211-214.

for school mathematics to improve the quality of school mathematics. As a result of the commission’s efforts, standards were drafted during the summer of 1987 and revised during the summer of 1988. Four working groups appointed by the president of NCTM outlined the draft documents. Each group represented mathematics educators, including classroom teachers, supervisors, educational researchers, teacher educators, and university mathematicians. All work was authorized and reviewed by the commission. In 1989 the *Curriculum and Evaluation Standards for School Mathematics* was published and widely disseminated (NCTM, 1989).

Three years after the standards were published, leaders in NCTM noted that many in their profession thought their identification of content in mathematics was too progressive so they appointed the commission of the future of the standards in 1995 to monitor and review the 1989 standards. By spring 1997, a Standards 2000 writing group and a Standards 2000 electronic format group were appointed, each consisting of teachers, teacher educators, administrators, researchers, and mathematicians. Their primary work was carried out in sessions during the summers of 1997 through 1999. The background information for these sessions was obtained or supported by such groups as Eisenhower National Clearinghouse, the NRC, the National Science Foundation, and NCTM’s research advisory committee. Over the course of the development of Standards 2000, 14 association review groups were formed to provide sustained advice and information regarding K–12 mathematics consistent with their organization’s perspective. In October 1998, a draft version of the standards was available in print and electronic forms for review. Twenty-five people from a wide range of backgrounds were commissioned to carefully review the draft from their individual perspective. Comprehensive reviews were conducted by more than 650 individuals and more than 70 groups. Nearly 30,000 copies of the draft were provided to interested persons, and thousands accessed the electronic copy. These data were synthesized and provided to a writing group which produced the final document that was disseminated as Principles and *Standards for School Mathematics in April 2000* (NCTM, 2000). See Table 2 for a listing of the content standards for mathematics.

Science

The success of standards in mathematics as well as Project 2061, sponsored by the American Association for the Advancement of Science (AAAS, 1993), caused leaders in science education to initiate the development of national science education standards. The National Science Teachers Association (NSTA) board requested the NRC to coordinate this important task. The U.S. Department of Education and the National Science Foundation provided major funding for this effort. An oversight group, National Committee on Science Education Standards and Assessment (NCSESA), was established. A chairperson was selected and a chair’s advisory committee was

Table 2. Mathematics Standards

1. Number and operations
2. Algebra
3. Geometry
4. Measurement
5. Data analysis and probability
6. Problem-solving
7. Reasoning and proof
8. Communication
9. Connections
10. Representation

Source: NCTM, 2000, pp. ix–xiii.

Table 3. Science Standards

1. Unifying concepts and processes
2. Science as inquiry
3. Physical science
4. Life science
5. Earth and space science
6. Science and technology
7. Science in personal and social perspectives
8. History and nature science

Source: NRC, 1996, pp. 13–15.

formed with representation from at least eight professional organizations. This group helped to identify and recruit staff and volunteers for the committees and three working groups (content, teaching, and assessment). Over an 18-month period, input on standards was received from a large number of teachers, scientists, science educators, and other interested parties. Many presentations were made to foster discussion on standards within the discipline. Then a predraft of science content, teaching, professional development, program, and system standards were written and critiqued by selected focus groups. The suggestions received were collated and analyzed, revisions were made, and a document was prepared for public release and review. Approximately 18,000 individuals and 250 groups reviewed this edition. The comments received were again collated, analyzed, and used to prepare the final publication of the *National Science Education Standards* (NRC, 1996). Table 3 includes the science content standards.

Cognitive and Process Standards in T/M/S

In comparing the technology/mathematics/science (T/M/S) content standards, it is interesting to note that science has the fewest with 8, mathematics has 10, and technology has 20. All three disciplines include within their designation of “content standards” standards that are clearly process oriented. Mathematics has the most process-oriented standards with 5; technology, 3; and science, 1+. The process standards in mathematics are problem solving, reasoning and proof, communication, connections, and representation; in technology they are apply the design process, use and maintain products and systems, and assess the impact of products and systems; and in science the primary process standard is science as inquiry, but science and technology has a process element as well. Of special interest is the fact that a discipline such as technology education that has traditionally been highly process oriented only developed three process standards. It can be argued that if these three processes are used in all seven contexts presented in “The Designed World” section, they actually will have high priority in the design of curricula.

Table 4 also shows the number of second-level statements (technology refers to them as benchmarks) in each set of standards, the grade bands in each set, the date the standards were issued, and the Web site where more information can be obtained. With several mouse clicks one can access the entire standards documents in mathematics and science. This makes accessibility quick and affordable.

Source

Each of the disciplines has strategies or standards that are designed to complement or help implement their standards. Along with content standards, science has developed teaching, professional development, assessment, program, and system standards. Mathematics has “principles” within their standards document to set forth the basic precepts that are fundamental to a high-quality mathematics program. The TfAAP has plans to develop assessment, program, and professional development standards by 2003. All three disciplines have implementation workshops or “institutes” to help teachers in the field learn to use the standards. Table 5 indicates topics included in the mathematics and science standards. Similar topics are under development for the technological literacy standards.

Table 4. Comparison of T/M/S Content Standards

Area	# of Stds	Second Level (9-12) Statements	Grade Bands	Date Issued	Website
TECH	17 cognitive 3 process	51 cognitive 15 process	K-2 3-5 6-8 9-12	2000	www.iteawww.org
MATH	5 cognitive 5 process	71 cognitive 18 process	PreK-2 3-5 6-8 9-12	1989/2000	www.nctm.org
SCIENCE	7 cognitive 1 process	27 cognitive 2 process	K-4 5-8 9-12	1995	www.nas.org

Comparison of Similar Standards

Each of the disciplines advocates a particular way to solve problems. In technology this is called design, in mathematics it is problem solving, and in science it is called inquiry. Science also includes design as a part of the science and technology standard. Table 6 illustrates these specific problem-solving strategies. Notice the overlap between the disciplines—particularly between technology and science. Also note the different way each discipline uses the word *connections* in Table 6.

The Impact of Standards on Technology, Mathematics, and Science Education

The impact of the standards for technological literacy is treated separately because there are unique issues. There are a number of positive developments. Support has been received from the engineering community (Gorham, 2002; Wulf, 2000); program standards (Martin, 2002) and assessment standards (Custer, 2001) are on schedule to be completed in 2003 (Dugger, 2001); the NSF has continued to fund the development of curricula based on standards (ITEA, 2002); some states are revising their standards (Mino, Kane, & Novak, 2001; Newberry, 2001); publishing companies are scrambling to produce new textbooks; workshops are being conducted on how to implement the standards[6]; some teacher education programs are changing to be more in alignment with the standards[7]; and new standards-based curricula are being developed by the discipline as well as the Center to Advance the Teaching of Technology & Science (CATTS), which is sponsored by the ITEA. However, many questions such as the following remain to be answered: Will technology education become a regular offering in the general education of all K–12 students? Will the human resources (teachers, administrators, teacher educators, etc.) be available to respond to the need for increased involvement in schools? Will technology education become more closely aligned with academic rather than vocational subjects?

The NCTM (not the federal government) identified the need for a common set of expectations so that states would have a guide to follow as they provided direction in preK–12 mathematics. Leaders in NCTM worked hard to develop a document that would be comprehensive and usable by the organization’s constituents. These leaders were actually surprised at the impact their first set of standards had.[8] Because of their success, other disciplines followed suit. Let us look at some of the ways mathematics and science standards have influenced education.

1. Nearly all states have used the curriculum

Table 5. Work Completed Beyond Standards

Technology	Mathematics	Science
To be developed (2003)	Principles	Teaching standards
	Equity	Prof. dev. standards
Assessment standards		
Program standards	Curriculum	Assessment standards
Prof. dev. standards	Teaching	Program standards
	Learning	System standards

and evaluation standards for school mathematics (NCTM, 1989) and national science education standards (NRC, 1996) when developing their own goals or frameworks for math and science for their state. One notable exception is in California where the science standards are more knowledge than process oriented.

2. Significant funding (National Science Foundation, Eisenhower, U. S. Department of Education, Science Literacy, etc.) for the development of mathematics and science curricula as well as for professional development has focused on the implementation of mathematics and science standards.

3. Nearly all textbooks in mathematics and science claim to be "standards-based."
4. Nearly all teacher education programs have changed to be in alignment with the standards. Discipline-specific National Council for the Accreditation of Teacher Education (NCATE) standards for accreditation are also congruent with these standards.
5. Manufacturers and vendors have designed, packaged, and marketed standards-based materials to support teaching and learning in math and science.
6. State and national leaders use the standards to lobby for more resources.
7. The state and national tests now purport to be based on mathematics and science standards. Now that there is common understanding as to what students should know and be able to do, the development and use of standardized tests has become more prevalent.
8. Both sets of standards advocate a new kind of pedagogy—one that is based on research in the areas of teaching and learning, cognitive science, and the function of the brain. This new pedagogy is

Table 6. Comparison of Similar Standards (9-12 BAND)

Technology	Mathematics	Science
Apply the design process • Clearly identify design problem • Identify criteria and constraints • Refine the design • Evaluate the design • Develop a product or system • Reevaluate solution	***Problem solving*** • Build new mathematical knowledge • Solve problems that arise in mathematics and in other contexts • Apply and adapt a variety of appropriate strategies to solve problems • Monitor and reflect on the process of mathematical problem-solving	***Science as inquiry*** • Identify questions and concepts that guide scientific investigations • Design and conduct scientific investigations • Use technology and mathematics to improve investigations and communications • Formulate and revise scientific explanations and models using logic and evidence • Recognize and analyze alternative explanations and models • Communicate and defend a scientific argument ***Science and technology*** • Define a problem or design an opportunity • Propose designs and choose between alternative solutions • Implement a proposed solution • Evaluate the solution and its consequences • Communicate the problem, process, and solutions
The relationships among technologies and the connections between technology and other fields • Technology transfer • Innovation and invention • Knowledge protection and patents • Technological knowledge and advances of science and mathematics and vise-versa (ITEA, 2000)	***Connections*** • Recognize and use connections among mathematical ideas • Understand how mathematical ideas interconnect and build on one another to produce a coherent whole • Recognize and apply mathematics in contexts outside of mathematics (NCTM, 2000)	***Science in personal and social perspectives*** • Personal and community health • Population growth • Natural resources • Environmental quality • Natural and human induced hazards • Science and technology in local, national, and global challenges (NRC, 1996)

referred to as "constructivism" and places emphasis on allowing students to use prior knowledge to new understandings through hands-on, authentic experiences. A careful review of Tables 7 and 8 will help the reader understand the shift in pedagogy from one that is knowledge-based (memorization) to one that engages students in science and mathematics for the purpose of building understanding.

9. The new pedagogy has made it necessary for teachers and administrators to engage in extensive professional development activities.
10. The new pedagogy has also made it necessary to make substantial improvements in facilities.

Personal Experience with Standards

As the director of the integrated mathematics, science, and technology middle school curriculum development project for the past 10 years, this author has had extensive experience in the use of T/M/S standards. Clearly, standards are not curriculum, but they are extremely useful for those who develop curriculum because (a) they provide the scope of content to be included, (b) they give an indication as to what students should know and be able to do for each grade band, (c) they indicate the topics to be included in each grade band, (d) they offer some guidance as to how much priority or time should be devoted to a given topic, and (e) they provide valuable input into the development of student assessments.

Of the three sets of standards, the mathematics standards have been the most useful for those who develop curricula. Each standard tends to be of equal importance, although some standards have higher priority in some grade bands. When one considers the preK–12 bands together, each standard tends to be of equal importance. Each standard is broken into approximately 70 developmentally appropriate subtopics, so it is very clear what students should know and be able to do as they reach the end of a grade band.

Science standards are less user-friendly because they are written in more general terms. In some cases this makes the determination of whether a learner has achieved a standard left to subjective judgment. When a standard has multiple components, the student may have achieved one aspect of the standard very well but another aspect less well. Then it is left to the curriculum developer or teacher to decide if more time needs to be spent on the achievement of the standard. Experience with aligning an integrated mathematics, science, and technology curriculum for at least 20 state frameworks reveals that national standards have influenced their state frameworks. However, in some states the national standards in both mathematics and science are broken down one more level to give more specificity and, thus, clarity as to what content children are expected to master by a given grade level.

The technology standards have definitely expanded the cognitive content to be mastered within the discipline. We have found that most of this added content can be integrated into the application of the three process standards. One problem with the technology standards is that they are inconsistent as to their scope. In other words, some are rather specific and can be mastered in a short amount of time and others are so comprehensive that it could take many class periods to accomplish. Also, the conceptual development of each of the standards from K–12 is in need of improvement. The author has used the standards for technological literacy (ITEA, 2000) on a daily basis since they were released, and he is most appreciative of the direction they provide. However, he would advocate taking a page from the mathematics educators who began to make plans for the revision of their standards three years after they were first released.

Summary

Since the mathematics standards published in 1989 had such a positive impact on the teaching and learning of mathematics, most academic disciplines have developed their own set of standards. In this era of accountability in preK–12 education, content standards play a central role. They define what students should know and be able to do. More and more they are used to develop standardized tests for specific grade levels. This is causing instruction and assessment to be squarely focused on standards, especially in the required subject areas. Although technology education is only required in 14 states (Newberry, 2001), the discipline is fortunate to have content standards and the resources to develop professional development, assessment, and program standards. Together these standards have the potential to make a positive impact on the technological literacy of future generations (Bybee, 2002).

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Table 7. Changing Emphases in Science Education

FEDERAL SYSTEM	
Less Emphasis On	**More Emphasis On**
• Financial support for developing new curriculum materials not aligned with the *Standards*	• Financial support for developing new curriculum materials aligned with the *Standards*
• Support by federal agencies for professional development activities that affect only a few teachers	• Support for professional development activities that are aligned with the *Standards* and promote system-wide changes
• Agencies working independently on various components of science education	• Coordination among agencies responsible for science education
• Support for activities and programs that are unrelated to *Standards*-based reform	• Support for activities and programs that successfully implement the *Standards* at state and district levels
• Federal efforts that are independent of state and local levels	• Coordination of reform efforts at federal, state, and local levels
• Short-term projects	• Long-term commitment of resources to improving science education
STATE SYSTEM	
Less Emphasis On	**More Emphasis On**
• Independent initiatives to reform components of science education	• Partnerships and coordination of reform efforts
• Funds to improve curriculum and instruction based on the *Standards*	• Funds for workshops and programs having little connection to the *Standards*
• Frameworks, textbooks, and materials based on activities only marginally related to the *Standards*	• Frameworks, textbooks, and materials adoption criteria aligned with national and state standards
• Assessments aligned with the traditional content of science education	• Assessments aligned with the *Standards* and the expanded view of science content
• Current approaches to teacher education	• University/college reform of teacher education to include science-specific pedagogy aligned with the *Standards*
• Teacher certification based on formal, historically-based requirements	• Teacher certification that is based on understanding and abilities in science and science teaching
DISTRICT SYSTEM	
Less Emphasis On	**More Emphasis On**
• Technical, short-term, in-service workshops	• Ongoing professional development to support teachers
• Policies related to *Standards*-based reform	• Policies designed to support change called for in the *Standards*
• Purchase of textbooks based on traditional topics	• Purchase or adoption of curriculum aligned with the *Standards* and on a conceptual approach to science teaching, including support for hands-on science materials
• Standardized tests and assessments unrelated to *Standards*-based program and practices	• Assessments aligned with the *Standards*
• Administration determining what will be involved in improving science education	• Teacher leadership in improvement of science education
• Authority at upper levels of educational system	• Authority for decisions at level of implementation
• School board ignorance of science education program	• School board support of improvements aligned with the *Standards*
• Local union contracts that ignore changes in curriculum, instruction, and assessment	• Local union contracts that support improvements indicated by the *Standards*
• Knowing scientific facts and information	• Understanding scientific concepts and developing abilities of inquiry
• Studying subject matter disciplines (physical, life, earth science) for their own sake	• Learning subject matter disciplines in the context of inquiry, technology, science in personal and social perspectives, and history and nature of science
• Separating science knowledge and science process	• Integrating all aspects of science content
• Covering many science topics	• Studying a few fundamental science concepts
• Implementing inquiry as a set of processes	• Implementing inquiry as instructional strategies, abilities, and ideas to be learned
CHANGING EMPHASES TO PROMOTE INQUIRY	
Less Emphasis On	**More Emphasis On**
• Activities that demonstrate and verify science content	• Activities that investigate and analyze science questions
• Investigations confined to one class period	• Investigations over extended periods of time
• Process skills out of context	• Process skills in context
• Emphasis on individual process skills such as observation or inference	• Using multiple process skills-manipulation, cognitive, procedural
• Getting an answer	• Using evidence and strategies for developing or revising an explanation
• Science as exploration and experiment	• Science as argument and explanation
• Providing answers to questions about science content	• Communication science explanations
• Individuals and groups of students analyzing and synthesizing data without defending a conclusion	• Groups of students often analyzing and synthesizing data after defending conclusions
• Doing few investigations in order to leave time to cover large amounts of content	• Doing more investigations in order to develop understanding, ability, values of inquiry and knowledge of science content
• Concluding inquiries with the result of the experiment	• Applying the results of experiments to scientific arguments and explanations
• Management of materials and equipment	• Management of ideas and information
• Private communication of student ideas and conclusions to teacher	• Public communication of student ideas and work to classmates

Source: National Science Education Standards, 1996, p. 113.

Table 8. Summary of Changes in Content and Emphases in 9-12 Mathematics

Topics To Receive **Increased** Attention	Topics to Receive **Decreased** Attention
Algebra • The use of real-world problems to motivate and apply theory • The use of computer utilities to develop conceptual understanding • Computer-based methods such as successive approximations and graphing utilities for solving equations and inequalities • The structure of number systems • Matrices and their applications	***Algebra*** • Word problems by type, such as coin, digit, and work • The simplification of radical expressions • The use of factoring to solve equations and to simplify rational expressions • Operations with rational expressions • Paper-and-pencil graphing of equations by point plotting • Logarithm calculations using tables and interpolation • The solution of systems of equations using determinants • Conic sections
Geometry • Integration across topics at all grade levels • Coordinate and transformation approaches • The development of short sequences of theorems • Deductive arguments expressed orally and in sentence or paragraph form • Computer-based explorations of 2-D and 3-D figures • Three-dimensional geometry • Real-world applications and modeling	***Geometry*** • Euclidean geometry as a complete axiomatic system • Proofs of incidence and between ness theorems • Geometry from a synthetic viewpoint • Two-column proofs • Inscribed and circumscribed polygons • Theorems for circles involving segment ratios • Analytic geometry as a separate course
Trigonometry • The use of appropriate scientific calculators • Realistic applications and modeling • Connections among the right triangle rations, trigonometric functions, and circular functions • The use of graphing utilities for solving equations and inequalities	***Trigonometry*** • The verification of complex identities • Numerical applications of sum, difference, double-angle, and half-angle identities • Calculations using tables and interpolation • Paper-and-pencil solutions of trigonometric equations
Functions • Integration across topics at all grade levels • The connections among a problem situation, its model as a function in symbolic form, and the graph of that function • Function equations expressed in standardized form as checks on the reasonableness of graphs produced by graphing utilities • Functions that are constructed as models of real-world problems	***Functions*** • Paper-and-pencil evaluation • The graphing of functions by hand using tables of values • Formulas given as models of real-world problems • The expression of function equations in standardized form in order to graph them • Treatment as a separate course
Statistics	Add to program
Probability	Add to program
Discrete Mathematics	Add to program

Source: NCTM, 1989, pp. 126-127.

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