Trajectories of Mathematics and Technology Education Pointing To Engineering Design

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Abstract

A brief examination and comparison of mathematics and technology education provides the background for a discussion of integration. In particular, members of each field have responded to the increasing pressures to better prepare students for the technologically rich, globally competitive future. Approaches based within each discipline are varied across curriculum and instructional strategies. However, when examining the disciplines' historical paths, there are important similarities to consider in determining how best to affect student learning in both mathematics and technology education. The authors contend that engineering design is the appropriate contextual area for integrating mathematics in technology education.

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The national learning standards associated with mathematics and technology education indicate a relationship between the disciplines of mathematics and technology education. Mathematics is referred to 30 times in the *Standards for Technological Literacy: Content for the Study of Technology* (International Technology Education Association (ITEA), 2000/2002) and technology is used over 20 times in the National Council of Teachers of Mathematics' *Principles and Standards for School Mathematics* (2000). For example, standard three in the *Standards for Technological Literacy* states that "students will develop an understanding of the relationships among technologies and the connections between technology and other fields of study" (ITEA, 200/2002, p. 44). The *Connections* standard in the *Principles and Standards for School Mathematics* states that students will recognize and apply mathematics in contexts outside of mathematics, and the *Problem Solving* standard reads that students will solve problems that arise in mathematics and in other contexts.

Both disciplines clearly include one another, at least in general terms. Their incorporation or relationship with each other appears to center on use. For example, upon review of these standards documents alone, the scope or purpose of technology in mathematics would appear to be that of instructional technology. Mathematics educators are primarily concerned with using technology to aid in instruction (e.g., computers, calculators, software) and facilitate student learning. Technology educators, on the other hand, are focused on how to use mathematics to understand, use, and design different technologies. Just as mathematics educators appear to see technology as a tool in service to solving mathematical problems, technology educators appear to see mathematics as a tool in service to solving technological problems (Merrill, Reese, & Daugherty, 2010).

However, does a closer relationship exist between the two disciplines beside the one-dimensional emphasis on use found in the standards? If a closer relationship were to exist, what might integrate the two disciplines? These two questions are the primary focus of this article. Moving beyond a simple analysis of standards documents, the historical trajectories of mathematics and technology education, as they relate to each other, are explored. By exploring these histories, a future point of integration through engineering design is explored.

Mathematics Education and Technology

Many reports have called for better preparation in mathematics and science, and for increased skills for the technology-rich workplace of the 21st century (American Association of University Women, 2000; Borgman et al., 2008; National Commission on Mathematics and Science Teaching for the 21st Century, 2000; National Mathematics Advisory Panel, 2008). Yet, many parents and teachers consider mathematics as a very traditional process of technology-independent practice, focused on algorithms, facts, procedures, and so forth. The history of technology integration into mathematics is embedded in the developments and debates about mathematics education in more general terms.

The "new mathematics movement" and the National Council of Teachers of Mathematics' (NCTM) standards-based reform are two movements that occurred within mathematics, with an era of "back to basics" in between (Herrera & Owens, 2001). The new mathematics movement developed in the 1960s in response to the launch of Sputnik and concerns over the nation's mathematical skills. The College Entrance Examination Board appointed a Commission on Mathematics, which developed a nine-point program that "called for preparation in concepts and skills to prepare for calculus and analytic geometry at college entry" (Herrera & Owens, 2001, p. 85), and it included sets, logic, algebraic structures, and pedagogical approaches of discovery.

The second movement focused on the NCTM Standards, which were released in 1989. The National Science Foundation (NSF) funded several curriculum development projects. These curricula emphasized conceptual learning, and many had a modular, thematic approach that integrated the content strands. For example, in a module of the Interactive Mathematics Program (Fendel, Resek, Alper, & Fraser, 2004) called the "Game of Pig," students work on probability, averaging, recognizing patterns, and making predictions through learning the rules of a simple dice game. In "Frogs, Fleas, and Painted Cubes," (Lappan, Fey, Fitzgerald, Friel, & Phillips, 1998) students explore quadratic relationships through area and perimeter problems. In general, the standards-based curricula had more hands-on activities and fewer drill and practice exercises. They also appeared at a time when instructional technology in mathematics was becoming more prevalent due to its increased power and decreased cost. Java applets, dynamic geometry software, and computer algebra systems are just a few tools that began to appear more frequently in classrooms in the 1990s.

In terms of technology, the mathematics standards made explicit that technology should be used in teaching, stating that, "appropriate calculators should be available to all students at all times," (National Council of Teachers of Mathematics, 1989, p. 8); this would enable students to focus on the problem-solving aspect, not simple computations. Recommendations at the high school level also called for the use of technology. The integration of ideas from algebra and geometry is particularly strong, with graphical representation playing an important connecting role. The standards also called for increased use of "computer-based explorations of 2-D and 3-D figures" and "real-world applications and modeling" (p. 126) as well as decreased attention to "paper-and-pencil graphing of equations by point plotting" and "paper-and-pencil solutions to trigonometric equations" (p. 127). Instructional technologies for the mathematics classroom were being developed and refined. The most dominant is the graphing calculator. Today, Texas Instruments sells over a hundred thousand calculators annually in the state of Illinois alone (personal communication, 2009). Software for performing mathematics calculations via computers has also been developed. Examples include dynamic geometry (Scher, 2000), computer-based algebra (Texas Instruments, 1997), and data analysis (Finzer, 2005).

In 2000, NCTM revised its standards, seeking to simplify and clarify their vision with the *Principles and Standards for School Mathematics (PSSM)*. The *PSSM* are the basis for most of the discussion and curriculum development in the mathematics education community today. The *PSSM* contain six principles (Equity, Curriculum, Teaching, Learning, Assessment, and Technology), five content standards (Number and Operations, Algebra, Geometry, Measurement, and Data Analysis and Probability) and five process standards (Problem Solving, Reasoning and Proof, Communication, Connections, and Representation). The standards are broken down by grade level and are expanded upon in the Navigations Series (e.g., Pugalee et al., 2002) and with online resources and articles in NCTM journals.

Today, the revised curricula that are based on the *PSSM* contain frequent technology applications. For example, the high school curricula College Preparatory Mathematics (Sallee & Hoey, 2002) and Core-Plus (Coxford et al., 1998) both have graphing calculators as important components of typical lessons. Programs such as the "Cognitive Tutor" (Hadley, 1998-2001) make extensive use of the computer. Even at the university level there are technology-rich options for learning mathematics. The Calculus & Mathematica course (Uhl, 2002), for example, has all lectures and homework assignments in the form of Mathematica notebooks. However, there is still very little data about how widely the reform curricula have been adopted and which curricula are most effective (National Research Council, 2004).

The *PSSM* will almost certainly continue to be the focal point for discussion and development in mathematics education, and technology is a crucial component of the *PSSM*. The "Vision for School Mathematics" described in the standards is still one in which "technology is an essential part of the environment" (National Council of Teachers of Mathematics, 2000, p. 3). Many of the exemplary lessons in the Navigations series include uses of spreadsheets, graphing calculators, and dynamic geometry programs. The *PSSM* are bolstered by online activities that include Java applets and other technologies. Graphing calculators are permitted on the SAT, ACT, and Advanced Placement mathematics examinations.

The role of technology in mathematics curricula and in mathematics teaching and learning has also been uncertain and contentious. A study by Wenglinsky (1998) looked at National Assessment of Educational Progress data and found that using computers, especially for drill and practice, had a negative correlation with student achievement in mathematics at the fourth and eighth grades. Yet, 10 years later, the report of the National Mathematics Advisory Panel included a statement that the use of technology is promising when "Computer-assisted instruction supports drill and practice" (Faulkner, 2008). And, of course, clarity is hindered by the reality that digital technologies are a moving target for impact studies. As growing numbers of students use cell phones, computers, MP3 players, and sophisticated video games, computer literacy might be assumed by mathematics teachers. Yet, many teachers remain unsure if technology is a ladder or a crutch for students (Brown et al., 2007), and best practices must evolve as the tools change.

Integration through Engineering Design

Through an examination of mathematics and technology education, several similarities are apparent, including that both disciplines have (a) developed learning standards, (b) make use of instructional technologies, (c) call for further study to discover more effective curricular and instructional approaches, (d) suggest contention within the ranks as to the purpose of the subjects, (e) see no reason to change from prior practices for some teachers and schools, (f) call for an applied/integrative/authentic approach, and (g) evolve, based on the needs of society (Merrill, Reese, & Daugherty, 2010). In addition to these similarities, there appears to be room for members of both disciplines to collaborate on developing effective practices centered on problem solving. The *PSSM* emphasizes the development of students' problem-solving skills in both abstract and applied contexts, as does the *Standards for Technological Literacy* (STL).

With the increasing national attention on science, technology, engineering, and mathematics (STEM) education (e.g., *Rising Above the Gathering Storm: Energizing and Employing American for a Brighter Future*, 2006), many have recognized the potential benefits of even stronger integrations across these disciplines. Perhaps the key point of future integration is engineering design, as a specific type of problem solving (Jonassen, 2000). Technology education has particularly moved to embrace an engineering-oriented perspective as an avenue to develop meaningful and authentic problem-solving capabilities in students. For example, Warner and Morford (2004) found in their study that 57 technology education programs offered coursework on the study of design. In addition, different initiatives, such as the NSF-funded National Center for Engineering and Technology Education (Hailey, Erekson, Becker, & Thomas, 2005), have been developed to infuse engineering into technology education. Numerous curriculum projects also have been initiated to incorporate various aspects of engineering, including an emphasis on design. A few of these projects include "Project Lead the Way™" (PLTW), "Engineering by Design," and "Engineering the Future: Science, Technology, and the Design Process.™"

The incorporation of engineering design into technology education has primarily emphasized a prescriptive, step-by-step model or a trial-and-error approach (Wicklein & Thompson, 2008). These approaches, however, have been criticized as simplifying the process of design and not being supported by research exploring how engineers design (Mawson, 2003; McCormick, Murphy, & Hennessy, 1994; Welch, 1999; Williams, 2000). The current technology education approach to engineering design often discounts or downplays the significant role of mathematical calculations in formulating designs (Wicklein & Thompson, 2008). As Lewis (2005) argued, a more analytic design approach, where the student relies upon mathematics and scientific principles to make decisions, "poses a challenge" (p. 48) for technology education. This is supported by McAlister's study (2005) of 44 technology teacher education pre-service programs, finding that only 17% of teachers had completed the mathematics requirements to teach "Project Lead the Way" courses.

Although there are many factors involved in engineering design, specifically isolating mathematics as an area that could use more attention within technology education, it could spur a closer integration across the disciplines. Through the examination of the historical trajectories of mathematics and technology education, it appears that the time may be right for a more fully integrated approach, whereby both disciplines approach engineering design drawing from each area's strengths, affecting student learning more fully. For example, Merrill, Custer, Daugherty, Westrick, and Zeng (2008) found in their study that high school students believe that mathematics (and science) concepts are better understood when they are connected to solving a problem or building an artifact.

The National Academy of Engineering Committee on K-12 Engineering Education pointed out that there is a reciprocal relationship between mathematics and engineering, whereby engineers use mathematics (and science) in their work, and mathematicians use the products of engineering in their work (Katehi, Pearson, & Feder, 2009). Engineers use mathematics in a variety of ways from describing to analyzing data, to building and analyzing models. The committee studied the status of K-12 engineering education and came to the conclusion that engineering could be the avenue toward the development of an effective and interconnected STEM education system. Although building a fully integrated STEM education system would require substantial structural changes to schools, the committee argued that engineering would "leverage the natural connections between STEM subjects" (p. 11).

Conclusion

There is a pressing need for relevance in all aspects of the curriculum, but especially in the STEM curriculum. In particular, mathematics education has continually struggled with relevance in terms of students' interests. Mathematics courses at the middle and high school levels often leave students unconvinced that the content is useful to their experience, let alone essential. And technology education has struggled with relevance to the core curriculum in schools and with image. As Merrill et al., (2008) pointed out in their study, "students take technology education courses because they are fun and activity-based, not mathematics or science-based" (p. 61). Integration through engineering design might address these issues of relevance within both disciplines.

John Dewey (1938, 1963) asserted that all education should be grounded in experience. Perhaps it is time to implement his approach with a deep connection between mathematics education and technology education. It is a premise of both disciplines that the ways in which mathematics or technology is taught is an essential component to how well students learn. Key to this notion is the authenticity of the task. That is, how closely do the problem situations in a classroom setting resemble those that are confronted by a mathematician, an engineer, or a mathematically and technologically literate citizen? It is clear that a connection between the two disciplines exists, but further collaboration, authentic learning activities, research-based findings, and above all, communication between the disciplines, needs to continue and flourish. In particular, each discipline should use a more holistic approach to problem solving (Moss, Osborn, & Kaufman, 2003). As Merrill and Comerford (2004) pointed out, "students will begin to see the 'connections or linchpins' that connect different fields of learning" (p. 10) through a more integrated approach.

Both communities would benefit from collaborative activities and research. Both disciplines' trajectories are aligning to make those efforts more feasible and necessary. There are well-established standards in both fields, and new programs have been developed to implement those standards. In addition, mathematics and technology education have had major curricular development efforts during recent years that should further a more intensive integration. A key opportunity for integration is presented in the new Common Core Standards Initiative (2010). The mathematics standards include modeling, both as a unique standard and as a topic integrated throughout the others. Students are expected to estimate, plan, design, model, analyze, and interpret. This effort coalesces with the call for mathematics to be a gateway rather than a gatekeeper (Bryk & Treisman, 2010) and with new curricula, such as the "Gateway to Engineering" (Rogers, Wright, &Yates, 2010) used in middle schools to integrate significant mathematics into the school curriculum through the introduction of engineering concepts.

The most important component is the depth of the connection. In a unified educational experience, the technology is not learned for the sake of the mathematics (as most educational technology in math is today), and the mathematics is not used merely to understand a piece of technology (unless one is inquiring into how it is made), but rather the educational ends should drive the united efforts. There is growing competition for space in the already-packed curricula of high schools. Students may be forced to choose, for example, between a pre-engineering course and an AP mathematics course; such a decision might be made for purposes other than the educational interests of the student, but rather for such concerns as test preparation or college admissions expectations. However, as Reeves (2009) commented, time in school should not be a "zero-sum game," where traditional electives like technology education exist as "extras" in the school curriculum – when time permits.

The school change literature (i.e., Fullan, 2005; Hargreaves & Goodson, 2006) advocates connections, yet they rarely occur. Why is this so difficult, and what could be done to change this? The two areas, mathematics and technology education, represent an evolution – the farthest ends of the STEM education spectrum. Mathematics education has grown from a place of unquestioned importance. Its utility as a tool for other scientific disciplines is undeniable ("the queen of the sciences," Gauss said of mathematics). This power has made mathematics education a test-based filter for academic success, and it has in turn become a contentious domain. Technology education evolved from roots in manual training, industrial arts, and career and technical education – the hands-on training for the non-college-bound student. Bringing these two disciplines together would have unique power and social significance, and engineering design seems a viable avenue for this type of integration.

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References

American Association of University Women. (2000). *Tech-savvy: Educating girls in the new computer age* (Executive Summary). Washington, DC: American Association of University Women. Retrieved May 12, 2010, from http://www.aauw.org/research/girls_education/techsavvy.cfm.

Borgman, C. L., Abelson, H. Dirks, L., Johnson, R., Koedinger, K. R., Linn, M. C., Lynch, C. A., Oblinger, D. G., Pea, R. D., Salen, K., Smith, M. S., & Szalay, A. (2008). *Fostering learning in the networked world: The cyberlearning opportunity and challenge, A 21st Century agenda for the National Science Foundation* (Report of the NSF Task Force on Cyberlearning). Washington, D.C.: National Science Foundation.

Brown, E. T., Karp, K., Petrosko, J. M., Jones, J., Beswick, G., Howe, C., & Zwanizig, K. (2007). Crutch or catalyst: Teachers' beliefs and practices regarding calculator use in mathematics instruction. *School Science and Mathematics, 107*(3), 102-116.

Bryk, A. S., & Treisman, P. U. (2010, April 18). Make math a gateway, Not a gatekeeper. [Commentary]. *The Chronicle of Higher Education.* Retrieved July 29, 2010 from http://chronicle.com/article/Make-Math-a-Gateway-Not-a/65056/

Committee on Prospering in the Global Economy of the 21st Century: An Agenda for American Science and Technology. (2005). *Rising above the gathering storm: Energizing and employing America for a brighter economic future.* Washington, DC: National Academies Press.

Common Core State Standards Initiative. (2010). *Common core standards for mathematics.* Retrieved June 13, 2010, from http://corestandards.org/assets/CCSSI_Math%20Standards.pdf.

Coxford, A. F., Fey, J. T., Hirsch, C. R., Schoen, H. L., Burrill, G., Hart, E. W., Watkins, A.E., Messenger, M. J., & Ristema, B. (1998). *Contemporary mathematics in context: A unified approach, Course 1A, Part A.* New York, NY: Glencoe McGraw-Hill.

Dewey, J. (1938/1963). *Experience and education.* New York, NY: Collier Books.

Faulkner, L. R. (2008). *Foundations for success: National Mathematics Advisory Panel (Final Report Briefing).* Washington, D.C.: U. S. Department of Education. Retrieved January 16, 2009 from http://www.ed.gov/about/bdscomm/list/mathpanel/report/report-presentation.ppt

Finzer, W. (2005). *Fathom:* Dynamic Data Software (Version 2.0): Emeryville, CA: Key Curriculum Press.

Fendel, D., Resek, D., Alper, L., & Fraser, S. (2004). *Interactive mathematics program: Integrated high school mathematics, Year 1.* Emeryville, CA: Key Curriculum Press.

Fullan, M. (2005). The meaning of educational change: A quarter of a century of learning. In A. Lieberman (Ed.). *The roots of educational change: International handbook of educational change* (pp. 202-216). Netherlands: Springer.

Hadley, W. S. (1998-2001). *Cognitive Tutor: Algebra 1.* Pittsburgh, PA: Carnegie Learning, Inc.

Hailey, C. E., Erekson, T., Becker, K., & Thomas, M. (2005). National Center for

Engineering and technology education. *Technology Teacher, 64*(5), 23-26.

Hargreaves, A., & Goodson, I. (2006). Educational change over time? The sustainability and nonsustainability of three decades of secondary school change and continuity. *Educational Administration Quarterly, 42*(1), 3-41.

Herrera, T. A., & Owens, D. T. (2001). The “new new math”? Two reform movements in mathematics education. *Theory into Practice, 40*(2), 84-92.

International Technology Education Association [ITEA}. (2000/2002). *Standards for TechnologicalLiteracy: Content for the Study of Technology.* Reston, VA: Author.

Jonassen, D. H. (2000). Toward a design theory of problem solving. *Educational Technology Research & Development, 48*(4), 63-85.

Katehi, L., Pearson, G., & Feder, M. (Eds.). National Academy of Engineering and National Research Council. (2009). *Engineering in K-12 education: Understanding the status and improving the prospects.* Washington, DC: National Academies Press.

Lappan, G., Fey, J. T., Fitzgerald, W. M., Friel, S. N., & Phillips, E. D. (1998). *Frogs, fleas, and painted cubes: Quadratic relationships.* White Plains, NY: Dale Seymour.

Lewis, T. (2005). Coming to terms with engineering design as content. *Journal of Technology Education, 16*(2), 37-54.

Mawson, B. (2003). Beyond ‘the design process’: An alternative pedagogy for technology education. *International Journal of Design Education, 13*(2), 117-128.

McAlister, B. (2005). *Are technology education teachers prepared to tech engineering design and analytical methods?* Paper presented at the International Technology Education Association Conference, Kansas City, MO.

McCormick, R., Murphy, P., & Hennessy, S. (1994). Problem-solving processes in technology education: A pilot study. *International Journal of Technology and Design Education, 4*(1), 5-34.

Merrill, C., & Comerford, M. (2004). Technology and mathematics standards: An integrated approach. *The Technology Teacher, 64*(2), 8-12.

Merrill, C., Custer, R.L., Daugherty, J., Westrick, M., & Zeng, Y. (2008). Delivering core engineering concepts to secondary level students. *Journal of Technology Education, 20*(1), 48-64.

Merrill, C., Reese, G., & Daugherty, J. (in press). Mathematics education. In P.A. Reed & J.E. LaPorte (Eds.), *Research in technology education.* Council on Technology Teacher Education 59th Yearbook, Woodland Hills, CA: Glencoe McGraw Hill. Moss, D. M., Osborn, T. A., & Kaufman, D. (2003). Going beyond the boundaries. (pp. 1-11). In D. Kaufman, D. M. Moss, & T. A., Osborn (Eds.). *Beyond the boundaries: A trandisciplinary approach to learning and teaching.* Wesport, Conn: Praeger.

National Commission on Mathematics and Science Teaching for the 21st Century. (2000). *Before it's too late: A report to the Nation from the National Commission on Mathematics and Science Teaching for the 21st Century.* Washington, DC: U.S. Department of Education.

National Council of Teachers of Mathematics. (2000). *Principles and standards for school mathematics.* Reston, VA: Author.

National Mathematics Advisory Panel. (2008). Foundations for success: *The final report of the National Mathematics Advisory Panel.* Jessup, MD: U.S. Department of Education.

National Research Council. (2006). *Rising above the gather storm: Energizing and employing America for a brighter economic future.* Committee on Science, Engineering, and Public Policy. Washington, DC: National Academies Press.

National Research Council. (2004). *On evaluating curricular effectiveness: Judging the quality of K-12 mathematics evaluations.* Washington, D.C.: The National Academies Press.

Pugalee, D. K., Frykholm, J., Johnson, A., Slovin, H., Malloy, C., & Preston, R. (2002). *Navigating through geometry in grades 6-8.* Reston, VA: National Council of Teachers of Mathematics.

Reeves, D. B. (2009). *Leading change in your school: How to conquer myths, build commitment, and get results.* Alexandria, VA: Association for Supervision and Curriculum Development.

Rogers, G., Wright, M., & Yates, B. (2010). *Gateway to engineering.* Clifton Park, NY: Delmar CENGAGE Learning.

Sallee, T., & Hoey, B. (2002). *College preparatory mathematics 1: (Algebra 1)*. Sacramento, CA: CPM Education Program.

Scher, D. (2000). Lifting the curtain: The evolution of Geometer's sketchpad. *The Mathematics Educator, 10*(1), 42-48.

Texas Instruments. (1997). Cabri Geometry II. Austin, TX: Texas Instruments.

Uhl, J. (2002). Calculus *& mathematica* [World Wide Web]. Retrieved April 21, 2002, from http://www-cm.math.uiuc.edu/

Warner, S. A., & Morford, L. L. (2004). The status of design in technology teacher education in the United States. *Journal of Technology Education, 15*(2), 33-45.

Welch, M. (1999). Analyzing the tacit strategies of novice designers. *Research in Science & Technological Education, 17*(1), 19-34.

Wenglinsky, H. (1998). *Does it compute? The relationship between educational technology and student achievement in mathematics.* Princeton, NJ: Educational Testing Service.

Wicklein, R. C., & Thompson, S. A. (2008). The unique aspects of engineering design. In R. L. Custer & T. L. Erekson (Eds.), *Engineering and technology education* (pp. 57-76). Council on Technology Teacher Education 57th Yearbook, Woodland Hills, CA: Glencoe McGraw Hill.

Williams, P. J. (2000). Design: The only methodology of technology? *Journal of Technology Education, 11*(2), 48-60.