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Editorial

Technology Education Research: Potential Directions

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Current educational reform proposals recognize the importance of understanding technology and have identified certain technological abilities as goals for all students. Important examples are the *Benchmarks for Science Literacy* of Project 2061 of the American Association for the Advancement of Science (AAAS, 1993) and the *Standards for Technological Literacy* of the International Technology Education Association (ITEA, 2000)[1]. In the international arena the United Nations Educational, Scientific and Cultural Organization (UNESCO) has also recognized the urgency of technology literacy throughout its *Innovations in Science and Technology Education* series.

The above reform movements call for understanding concepts and principles of technology such as design, control, and systems and also some important ideas about technology in specific areas such as materials, energy, and communication (AAAS, 1990; ITEA, 2000). In doing so they are transforming the field of technology education, within a context of literacy, asking for a deeper understanding of the nature of technology. This transformation has important implications for any potential research agenda for technology education.

Project 2061 of the American Association for the Advancement of Science (AAAS) held a conference to consider what kind of research would enhance the goal of achieving universal technological literacy. Last December, thirty-five participants from science education, technology education, and cognitive science convened to discuss the role of research in technology education. Technology was discussed from a wide perspective, including the relationship between science and technology, the notion of design, control mechanisms, materials, energy, and communication. The overall goals of the conference were to raise consciousness on the needed research and to begin a discussion for a research agenda in technology education.

The American Association for the Advancement of Science has long recognized the importance of technological studies in the education of all Americans. Since 1985 Project 2061 has been promoting literacy in science, technology, and mathematics ("science literacy" for brevity). In *Science for All*

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Americans, Project 2061 recommended ideas and skills for adult science literacy. *Benchmarks for Science Literacy* suggested specific attainments in grades K-12 along the way toward science literacy. In thinking about students' developmental patterns, the Project 2061 staff has long felt the need for research on how students learn specific ideas and skills, particularly in the study of technology. Therefore we want to encourage research on when and how students can achieve specific literacy goals (AAAS, 1998). This conference called for an evaluation of the role of research in technology education in promoting technological literacy.

Origins of the Conference

In early 1999, Gary Benenson, Professor of Mechanical Engineering, City College, NY, and Fernando Cajas, Researcher, American Association for the Advancement Science/Project 2061, established an on-going dialogue about the importance of technology education research. In developing curriculum materials, Benenson and his team have felt the need for research in technology education to guide their work. This feeling is shared by other technology education projects funded by the National Science Foundation (NSF). In Project 2061 the situation is similar. There is a need for good research in technology education to shed light on how students' understanding and abilities grow over time.

The conversation about research in technology education was expanded to a group of technology educators who became members of the planning committee for this conference[2]. The committee met in Washington, DC, to develop a preliminary agenda. The two main issues discussed in this meeting were:

1. Developing a research agenda that can support technology education for all.
2. Setting priorities for research in technology education.

The invitation for the planning committee included the following specific issues and particular research questions:

- What steps could be taken to make a case for technology education in the K-12 curriculum?
- What are the core concepts in technology education?
- Should integration with other subjects (e.g., science courses) be a priority for technology education?
- Who are the technology education teachers and who are the students?
- How do children learn technological concepts (e.g., design under constraint)?
- What kind of research is needed to support the creation of good curriculum materials to teach the big ideas and skills in technology education?

The Conference: A First Glance

The conference was framed around four issues: Research Areas, How Children Learn Technological Ideas, Research Methods, and Assessment.

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From the beginning, the conference produced meaningful discussions. After an opening technology activity (Benenson) and during a presentation on how technological ideas and skills might progress from K to 12 (Soren Wheeler, AAAS/Project 2061), participants engaged in an intense discussion about the difficulties of teaching ideas of systems. Discussions highlighted the tension between knowing and doing in technology education which is related to the important distinction between knowing about technology and doing technology. The knowing/doing theme was part of many other discussions in the conference and was linked to the need for research about effective ways to learn technology.

The issue of "Research Areas" was addressed in several presentations and discussions. Robert McCormick (Open University, UK) suggested specific areas of research such as the distinction between procedural and conceptual knowledge in technology education. Using the context of mapping technological ideas, Soren Wheeler (AAAS/Project 2061) called for developing a picture of the progress of understanding of technological ideas and skills from grades K to 12 and the need for cognitive research that explains how students develop this understanding. Karen Zuga (Ohio State) suggested that there may be cultural differences in how students learn and what they know about technology. But we still do not know what children learn about technology. Although Zuga and W. Tad Foster (Indiana State University) presented an account of the kind of research that has been done in technology education, this research has not explored what children are learning about technology.

The second issue, "How Children Learn Technological Ideas," was addressed by McCormick's and Patricia Rowell's (University of Alberta, Canada) research about how students learn. Participants and presenters also spent time on "Research Methods" and "Assessment." Theodore Lewis, professor at the University of Minnesota and currently at NSF, and Karen Zuga called for methods in technology education research that depart from the traditional quantitative approach. Janet Kolodner (Georgia Tech) called for more attention to asking the right research questions and using "design experiments" to better understand students' learning. Kolodner's presentation connected the "Research Areas" and "Research Methods" issues. According to Kolodner, research methods should include clinical interviews, discourse analysis, and ethnographies of classrooms.

"Assessment" was addressed in nearly all of the presentations and discussions. Rowell presented her on-going research on how to assess students' understanding of technological tasks and presented data from several case studies that showed knowledge gain. Edward Goldman, a high school teacher from Brooklyn Technical High School, NY, and Dorothy Bennett, an evaluator from Education Development Center, Inc. (NY) reviewed the difficulties of assessing students' understanding of specific technological ideas. For example, they discussed the problems of assessing students' consideration of trade-offs in designing a chair. They used some samples of students' work and discussed the limitations of focusing only on the final product designed. On several occasions, Bennett and Goldman stressed the importance of the collaboration between teachers and researchers.

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Reflections

After the conference, participants where invited to reflect on the issues discussed. Several participants shared their thoughts in writing. The reflections focused on whether or not the conference changed or inspired the participants' thinking about research in technology education and what specific next steps need to be taken to focus a potential research agenda for technology education. Each reflection presents thoughts, concerns, and inspirations concerning research addressing technological literacy, with implications for K-12 technology education. These reflections provide a basis for further dialogue and focused research efforts.

What follows is a description of the reflection papers that were presented after the conference. Several papers provide a good description of what happened in the conference (B. Valesey, ITEA). Other papers provide some general directions for research in technology education (R. McCormick). And all of them raise critical issues for thinking about research agendas in technology education. The reflections provide suggestions for needed research, such as:

- Priorities need to be set for what to research, how to research, and where and when to research. A productive research agenda should be planned around student learning of key technological ideas (concepts) and skills (processes) identified for literacy (AAAS, 1993; ITEA, 2000).
- There is a need to do research on how well curriculum materials and classroom instruction actually help students to learn specific technological concepts and skills.
- Research in science and mathematics education and cognitive research in general can be used as models, but it is important to recognize that the issues in technology are different from those in science and mathematics. As research in technology education develops, however, technology education researchers should look for ways to work on common issues with researchers in science and mathematics education.
- It is important to study how teachers themselves understand—and come to understand—technology.
- Research needs to be done to determine the most efficient and cost effective ways to conduct professional development of technology educators.
- Educational research methods can vary greatly, e.g., from traditional surveys to design experiments, from multiple choice questions to in-depth interviews. Case studies would be useful to create an adequate basis for later formal research.

Perhaps the most striking feature of the reflections is that several do not set, nor even mention, priorities. There is a tendency to suggest areas of research without providing a rationale about why one should be prioritized over another. The only exception to this was the reflection by Senta Raizen (The National Center for Improving Science Education). Pam Newberry (ITEA) reminded us about the importance of priorities, stating that, "Time is an issue not just for the school curriculum, but also for planning and developing a research agenda…." We not only have to clarify the areas of research, but also need to provide an

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argument for which area is most urgent. This is a difficult task, but setting priorities should be a priority itself. For instance, Dorothy Bennett suggested three core areas for further investigation in technology education: Technology Teaching Pedagogy, Student Learning, and Teacher Development. How should we prioritize Bennett's areas of research? If we agree with Andrew Ahlgren (AAAS/Project 2061) that "…student learning is by far the highest priority to study," we may want to consider the following framework:

1. Specific goals for knowledge and skills students will learn.
2. How students learn those ideas and skills.
3. Shaping instruction to promote student learning.
4. Enabling teachers to teach that way effectively.

This priority has a clear rationale: until we learn more about what we want students to learn, what students know and how they learn it, we are not prepared to study instructional methods. And until we learn more about what kinds of instruction are effective, we are not prepared to teach teachers how to do it.

Specific Goals for Learning

For several participants, the question of what everybody should learn in technology education is not problematic. They are aware of how technology ideas and skills have been introduced in current curriculum-reform documents. Franzie Loepp (Illinois State University) and Foster looked to how the new *Standards for Technological Literacy* (ITEA, 2000) are affecting potential areas of research. Other participants pointed to the high priority for determining what specific ideas and skills students should be learning. In pointing out what students should learn about design, Kolodner suggested:

> This requires going back to the design cognition literature and seeing what it says about designing (i.e., identify the practices of expert designers that we might want students to learn). Then asking what, of those skills and concepts, we want students to be learning. Then going to the developmental literature and looking at what it is they might be able learn at certain times in order to build up to this thing you want to get to.

This is an admirably rational plan, which has been implemented during the past decade by at least three institutions: The American Association for the Advancement of Science, the National Research Council, and the ITEA. In the case of AAAS's Project 2061, hundreds of scientists, mathematicians, engineers, physicians, philosophers, historians, and educators collaborated over three years in writing reports that were the basis for *Science for All Americans*, which includes literacy in technology and mathematics as well as in natural and social sciences. There is also a specific Project 2061 report on Technology Education (Johnson, 1989). These reports looked into the nature of technology and design and considered what of that all students should be expected to learn. *Science for All Americans* has at least two full chapters dealing with technology, where specific ideas and skills concerning design, trade-offs, systems, feedback and control, redundancy, and cost/benefit considerations, are clarified. Project 2061's *Benchmarks for Science Literacy* was a second step towards literacy in

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science, mathematics, and technology based on the best educational research available on what students could learn and when. In *Atlas of Science Literacy* (AAAS, in press), Project 2061 has now taken the recommendations a step further in making maps of how students' understanding would grow from kindergarten to graduation.

National Science Education Standards (National Research Council, 1996) includes some ideas about technology. *Standards for Technological Literacy*: *Content for the Study of Technology* (International Technology Education Association, 2000) is the latest attempt to clarify what everybody should learn about technology. This document appears to have substantial overlap with *Benchmarks*. With the support of the National Academy of Engineering, the technological literacy standards will be a catalyst for the introduction of technology in general education. These documents may need work, but they can be used as a starting point and as necessary common ground.

Despite this consensus on the ideas and skills all students should learn, during the conference there was a spirited discussion about the relationship between knowing and doing in technology education and the effect that this distinction has on what we want students to learn. This tension also shows up in several of the reflections. James LaPorte (Virginia Tech) suggested that "…technology is quite different from science, mathematics, and other core school subjects. The difference is that the essence, the very soul, of technology education is *doing*…. The point here is that a hands-on teaching method is not just a matter of sound pedagogy for technology education. Rather, *doing* (or practice) forms the core of the content of the field."

In regard to the knowing and doing discussion, Kenneth Welty (University of Wisconsin-Stout) laid out a challenging metaphor that examined the difference between an "adventure" and a "journey." An adventure in technology education was characterized as an exciting and potentially rewarding activity that is initiated without any specific intellectual expectations for students. The merits of this approach tend to surface during reflections on the experience. A journey, on the other hand, was described as an activity that has a specific destination in mind. From his perspective, the destination should be the mastery of a profound idea or the development of an essential skill. Welty purports that technology teachers have an affinity for adventures that are launched without sufficient thought about how the student will be different when they are over. With adventures, the attainment of specific goals tends to occur more by default than by design. Technology education will become more valued, he claims, when its activities are designed as journeys toward well-specified outcomes. We believe he respects the value of adventures with technology, but he also values the finite amount of time that is available in the curriculum (even under the best of circumstances).

Thus he believes future research needs to focus on how teachers can best use their precious time to engage young people in journeys (engaging activities) that reach predetermined destinations (the attainment of standards).

How Students Learn

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Several participants pointed to specific topics in student learning. McCormick called attention to problems in learning about systems: "Systems knowledge, recognized in *Benchmarks* as conceptual knowledge, is very abstract." This raises the empirical question of how, when, and under what conditions children can learn specific ideas about systems.

There are other problems related to what technological ideas and skills should be a part of technological literacy. Bennett identified central questions in this area. For example: "What types of problem solving strategies do students employ in design problems?" Drawing on his work on problem solving, McCormick reviewed the status of this research in England, where they have found that students follow rigid algorithms reminiscent of the fictional ritual of the scientific method:

> First we often treat design or problem solving as a series of steps. An 'algorithm' notion of design or problem solving characterizes it as consisting of posing the problem and thinking about the problem, clarifying it, thinking of alternate solutions, implementing it, and then evaluating it. This can become a *ritual*…that does not affect the student's thinking.

Despite the research on design and problem solving, we still do not know how children learn specific ideas about design, trade-offs, constraints, redundancy, etc. The work from England may illuminate what we are trying to do in America, but in the U. S. we want students to learn specific ideas about design as well as some basic skills in designing things. In the U. K. there is more emphasis on the "processes," such as the ability to actually design things.

Finally, studying how children learn specific technological ideas and skills will require not just paying attention to research on particular technology topics, but also taking a closer look at the general cognitive research literature. Crismond presented a general overview of the origins of the research tradition of cognitive science and how this experience can help us to think about a research agenda. Hutchinson suggested taking a look at other fields of research as well. We also need to learn from research in science and mathematics education, including its limitations (among others, Ahlgren, Kolodner, and Zuga make this point. See also Schoenfeld, 1999).

Instruction

During the last ten years there have been important developments in the study of teaching, particularly the kind of teaching that current science and mathematics education reforms are advocating (see Lagemann and Shulman, 1999 for a review). This research is helping us to realize that teachers will have to unlearn much of what they believe, know, and do, as Thompson and Zeuli (1999) pointed out:

> The key questions for reform, then, are whether teachers understand that students must think in order to learn and whether they know how to *provoke, stimulate, and support students' thinking*…. That students must think in order

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> to learn may seem blatantly obvious. But if it is so obvious, why do so many teachers–in fact, nearly all teachers–fail to see it? (p. 349, italics added)

Science and mathematics education researchers have spent decades dealing with problems of student learning. Researchers in the technology education community need to learn from this. Progress in science and mathematics began only after researchers started asking what science and math ideas and skills students really understood. Then, they moved to developing, on a very modest scale, instructional activities that strongly connected instruction and content. Instructional design was followed by classroom trials, revised, tried again, until students showed successful learning of what was intended. The National Council of Teachers of Mathematics has taken advantage of their research on learning and explored its implications for teaching (for example, the series *Research Ideas for the Classroom,* Jensen, 1993; Owens, 1993; Wilson, 1993). Science education has a similar series *What Research Says to the Science Teacher.*

The situation in technology education is different. Take the example of design. A review of the literature on design indicates that researchers have explored how children design things (Makiya & Rogers,1992), the iterative nature of the design process (McCormick, Murphy, & Hennessy, 1994); and how children's design ideas are related to their technological activities (Fleer, 1999). However, there is almost no research on how children learn about design principles (trade-offs, constraints, redundancy, overdesign, and failure). Research can help in providing information about what ideas students have about design and how these ideas can either help or obstruct their learning. Research would help teachers and curriculum developers to develop instructional activities that guide students' thinking toward these ideas by providing relevant phenomena and useful questions that can motivate, stimulate, and support students.

Many reflections also call for a stronger connection between research and practice, particularly in the classroom (Benenson, McCormick, Rowell, and Valesey pointed out this issue in their reflections). For example, what role should research play in developing curriculum materials such as field testing activities in a classroom setting? Kolodner focused on research questions and methods in the context of developing curriculum materials. She acknowledged the need for several research strategies, including what she called a "design experiment" (Brown, 1992). Assuming that research has to be conducted in complex settings, particularly in the context of curriculum materials development, she called for powerful methods to do research not only on learning, but also on teaching:

> A design experiment bases research in classrooms. Basically, what happens in a design experiment is that you, the researcher, engineer the environment to promote learning. What you do is to take what you know about learning and about practice, and put those together to figure out what you think should be happening in the classroom in order to promote the kinds of learning that you're aiming for…. Design experiments allow you to do research on student

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> and/or teacher learning, to analyze the learning environment in ways that lead to useful refinements, and to learn how effective your classroom approach is–all at the same time.

Such an effort requires combining two difficult research areas: one on student learning and the other on teacher learning. The feasibility of this kind of research and where it lies in the hierarchy of priorities need further discussion.

Teacher Development

Loepp called for studying the quality of professional development programs. Meaningful outcomes from such a study, however, depend on an understanding of how teachers learn. Benenson reflects on the need for studying teachers' thinking:

> This conference focused on children's cognitive development. An equally important set of questions has to do with how *teachers* understand and come to understand technology. Research on teachers' conceptual and procedural knowledge should both inform and be pursued in parallel with professional development.

The suggestion is that professional development programs could become a focus for studying how teachers learn to teach specific technology ideas and skills. This kind of work will be impossible without having a solid foundation on how students learn those specific technology concepts and skills. In the mathematics education community, research on and for professional development is just emerging (Greeno et al., 1998). The reason for this recent shift to research on the professional development of teachers is the prerequisite accumulation of knowledge on student learning. It is possible that the technology education community can find a way to speed up its research on student learning, instruction, and professional development, but further discussion is needed.

Concluding Comments

In his reflections about the conference Kenneth Welty pointed out that a common practice in technology education is to engage students in rich activities that are grounded in time-honored practices. He suggested that one new focus for a research agenda would be to study what students are learning from those activities. He also stated that instead of studying current teaching practices in hopes of uncovering content worth learning, our research agenda should focus on how students learn the deep understandings and essential skills for technological literacy. This idea is simple but revolutionary.

The conference and the reflection papers are a small step in the direction of enabling individuals to begin serious dialogues on making progress in research on technology education. However, there were important issues that did not get discussed. In the reflections that Foster wrote, he discussed the limits of time, personnel, and funding available. He argued that a collaborative focus on a small number of high-priority topics was needed. Mark Sanders (Virginia Tech)

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pointed out the lack of researchers. This is a critical problem for the development of any research agenda. Sanders suggested that this could be overcome by creating an Internet/Web based graduate class to encourage action researchers who might collectively pursue a research problem during the course. Considering the resources and constraints, priorities must be set if progress is to be made.

A second conference on technology education research is being planned. It will be structured around selected issues identified in the first conference. The goal is to stimulate research on students' understanding of specific technological ideas and skills that have been identified for literacy. In framing this conference we will use the proceedings from the first AAAS research in technology education conference and the experience accumulated from other events such as the International Technology Education Association/NSF Forum on Research in Technology Education held in Salt Lake City during the 2000 ITEA Annual Conference. The goal of the second conference is to build on the conversations initiated in the first conference and move toward doing research that can enhance the goal of technological literacy for all students.

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Notes

1) The American Association for the Advancement of Science (AAAS, pronounced "Triple-A-S") is the world's largest science organization. Project 2061/AAAS is a long-term science, mathematics, and technology education reform initiative that benefits K-12 students.
2) The conversation was extended to the following individuals: Dan Householder (Iowa State University), Ted Lewis (University of Minnesota, NSF), Franzie Loepp (Illinois State University), Pam Newberry (ITEA), Bridgette Valesey (ITEA), and Ken Welty (University of Wisconsin-Stout).
3) The Proceedings are available through the Website of Project 2061/AAAS: www.project2061.org/technology.

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