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Research on Teaching and Learning in Science Education: Potentials in Technology Education

Chapter 10

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> *Learning is personal, contextualized, and takes time. To be successful, teaching must attend to each of these criteria and be grounded in the knowledge of practice, the learner, and the learning process.*

INTRODUCTION

This chapter presents a discussion around contemporary teaching and learning research in science education that holds promise for informing the educational research efforts on classroom practices in technology education. Ultimately, the goal of this chapter is to highlight select genre of science education research that are compatible with, and parallel to, areas of needed research on the teaching/learning practices in technology education. The approach begins by first presenting the framework around which science education research has been organized, followed by highlighting strategic areas of pedagogical crossover, and concluding with attention to select research efforts in science education regarding the linkages between the teaching/learning (pedagogical) process and teacher knowledge. The intent is to draw on various aspects of science education research as a means of encouraging new perspectives on organizing the investigation of educational practices in technology education.

Historically speaking the connection between science and technology has long been established with broad acceptance of the reciprocal impact of developments in one field on advancements in the other. In education, the potential for using those connections to improve students' science and technology literacy and to instill a deeper functional understanding of content in both areas is today well recognized. Yet of these two school subjects, science is a nationally established core content area, while technology is typically relegated to an elective. There is a deep societal discrepancy in perceived value of the teaching and learning outcomes afforded students by these two school disciplines, which to some degree is empirically supported. In science the connection between value and empirical evidence is clearly conveyed in the science assessment framework: "Science is a way of knowing about the natural world that is based on tested explanations supported by accumulated empirical evidence" (NAGB, 2008 p. 10). Educational research is one of the primary vehicles through which school disciplines establish the credibility of their programs for promoting student learning of core knowledge and skills at the PK-12 level. In science education one cannot but be impressed by the scope of research on teaching and learning published by those in the field for nearly a century. The shear number of science education researchers makes possible a breadth and depth of empirical investigation not afforded the emergent field of technology education.

Cognizant of the important relationship between empirical evidence and valued pedagogical practice, researchers in technology education have repeatedly sought to document an empirical framework for the field. Prior analyses of published research in technology education over the past several decades (McCrory, 1987; Waetjen, 1992; Foster, 1992, 1996; Zuga, 1994, 1995, 1997; Petrina, 1998; Lewis, 1999; Hoepfl, 2002, 2007) revealed significant gaps in the research needed to establish the viability of pedagogical practices in technology education. The most recent analyses and summary assessments (Johnson & Daugherty, 2008; Wells, et al, 2008, 2009) of published technology education studies further verified previous findings regarding those gaps in technology education research. This chapter focuses on three of the identified gaps in technology education research – design-based teaching/learning, integrative practices, teacher knowledge – that have particular relevance to areas of teaching and learning research conducted in science education. These gaps align well with analogous topics addressed within the genre of learning theory and pedagogical practice around which science education research has been organized, and serve as the framework for discussions in this chapter.

In a field not accustomed, or perhaps even prepared to conduct such challenging research along the lines and at the level called for (Zuga, 2001), technology education researchers would benefit from better understanding the approach to educational research in other school disciplines having similar/corollary practices, related educational standards, and close historical connections to the field of technology education (Lewis, 1999). Science education represents a school discipline that has long historical ties with technology education and strong parallels in both content and pedagogical practices. Drawing on the structure of teaching and learning research in science education has potential for providing direction for the types of research in technology education necessary for developing its credibility as a school subject. For these reasons science education is ideally suited to providing insights for developing the necessary framework of research needed in technology education to empirically document its viability as a school subject that contributes substantively to learning of core concepts/content at the PK-12 level.

The current framework used to organize research on science education is logically aligned with the National Science Education Standards (NSES)

(NRC, 1996) and the science assessment framework for 2009-2021 developed by the National Assessment Governing Board (NAGP, 2008). To understand the alignment of frameworks calls for some discussion that will provide a basis for envisioning similar alignments to frame the educational research agenda in technology education.

SCIENCE EDUCATION: ASSESSMENT, STANDARDS, AND RESEARCH FRAMEWORK

> "…we will only be effective if we begin with the end in mind." — *S. Covey*

To achieve a learning goal, one structures the instructional process by beginning with the end in mind; i.e. what is to be learned and how will achievement of that learning be assessed? Assessment seeks to measure the degree to which the learner achieves a stated outcome (end) (Linn & Gronlund, 2000). The "ends" identified in the 2009-2021 framework for the national assessment of science education progress (NAGB, 2008) are structured around two broad dimensions - content and practice - both of which were based on the 1996 NSES and benchmarks. The 2009 NAEP science framework defines the content dimension through a series of content statements that describe the key principles, concepts, and facts which are organized according to three content areas: physical science, life science, and earth and space science. Likewise, four practices define the practice dimension: identifying science principles, using science principles, conducting science inquiry, and using technological design (p. 21-22). Dividing the assessment across only the dimensions of content and practice both simplifies and clarifies the main "ends" of the educational process – what students should know and be able to demonstrate.

In science education the content dimension is defined by the following three broad areas: physical science, life science, and earth and space science. To assess student learning in these areas proposition statements were developed by the NAGB (2008) to reflect the key principles, concepts, and facts for each content area. The proposition statements alone do not describe the learner's performance in observable terms. To do this they must be crossed with science practices so as to generate performance expectations, which ultimately allow for inferences to be made about what the learner knows and can do in science. Crossing content areas with practices allows for both to be assessed concurrently, with comparisons made between expected performances and observed performances (Figure 1). As a result, assessment of performance outcomes can then be used to gauge student achievement across three levels: basic, proficient, and advanced (NAGB, 2008). These become the three primary levels used for data collection and reporting of findings on student achievement to the various stakeholders about what students know and are able to do in science.

		Science Content		
		Physical Science content statements	**Life Science** content statements	**Earth and Space Science** content statements
Science Practices	**Identifying Science Principles**	*Performance Expectations*	*Performance Expectations*	*Performance Expectations*
	Using Science Principles	*Performance Expectations*	*Performance Expectations*	*Performance Expectations*
	Conducting Scientific Inquiry	*Performance Expectations*	*Performance Expectations*	*Performance Expectations*
	Using Technological Design	*Performance Expectations*	*Performance Expectations*	*Performance Expectations*

Figure 1. Crossing Content and Practices to Generate Performance Expectations

By design, this assessment structure provides the basis for researching connections between pedagogical practices (science teaching) and student achievement (learning science). Technology education, because it is nationally assessed to such a limited extent, lacks this type of data and assessment structure. As a result, this is one main reason the profession has been unsuccessful in developing its own unified framework for research into the impact of teaching practices on the technology content and practice outcomes (learning) that students should be expected to demonstrate across grade spans. However, a critical change regarding the practice of employing technological design in the NAEP 2009 Science Framework presents technology education with a significant research opportunity. The NAGB clarified its position regarding technological design as an assessment practice by stating "Because NAEP addresses the subject area of science, the use of technological design components in the 2009 NAEP Science Assessment will be limited to those that reveal students' ability to apply science principles in the context of technological design." (NAGB, 2008, p. 76). The Framework views technological design as a vehicle for learning science content and concepts, with no attention to learning or assessing concepts of technological design. This realm of assessment can and should be championed by researchers in technology education.

Predicated on the National Science Education Standards and benchmarks (NRC, 1996), the NAEP 2009 science framework provides a mechanism for assessing the targeted performance and learning expectations within the content and practice dimensions across grade spans. The structure around which research on science education has been organized aligns with the NAEP 2009 science framework and is designed to assess the capacity of science education for achieving the outcomes expressed in the standards and benchmarks; i.e. research into the science teaching and learning processes to better understand how well the "educational ends" are being achieved. Clarity of assessment affords an equal clarity of pedagogical practices necessary for achieving the educational ends, and around which research on science education (teaching and learning) has been logically organized.

FRAMEWORK OF RESEARCH ON SCIENCE EDUCATION

Reviews of science education research have been available to the science community since the late 1920s and were regularly summarized in research digests up until 1957 and then republished in 1971 as a six-volume set by the Teachers College Press. Summaries of the science education research after 1957 continued to be published as chapters of the *Handbook of Research on Teaching* as well as various reports supported through the National Association for Research and Science Teaching (NARST) published by the ERIC Science, Mathematics, and Environmental Clearing House. However, a comprehensive analysis of research on science education did not occur until 1994 when the first *Handbook of Research on Science Teaching and Learning* was published (Gabel, 1994). This single volume was the first attempt to synthesize research over an extended period of time and provide the science education research community with a clearer picture of the content addressed and methods used. As reflected in the title, science teaching and learning were the guiding themes of the handbook and addressed in two sections with three chapters each. Significant attention was also placed on problem solving, with an entire section, six chapters, devoted to this topic. Two additional sections were developed around curricular and contextual issues relating to the instructional environment. The purpose of the handbook was to synthesize past research as a means of better understanding the teaching and learning practices of science education and to set the course for continued science education research. In 2007 the *Handbook of Research on Science Education* (Abell & Lederman, 2007) was presented as a comprehensive synthesis of empirical and theoretical research concerning teaching and learning in science education, and with an expressed purpose of providing a foundation upon which future science education research could be built.

Research on science education is presented in the 2007 handbook as a progression that begins with learning theory and proceeds toward pedagogical practices as instilled through teacher preparation. This was an intentional effort to provide more coherence of purpose and unify future directions among investigations conducted by science education researchers. This progression is framed by three themes – Learning Theory, Research Methods, and Pedagogical Practices – that together provide the agenda and priorities for research in science education. Throughout the past century the main learning theories of the time can be shown to strongly influence science education research and knowledge of the teaching/learning process. In a reciprocal fashion, gains in knowledge lead to changes and improvements in research methods, which in turn improved understandings regarding how learning science occurs. For example, one key realization affecting science pedagogy is that the teaching and learning of science is found to be "discipline specific," and indicates that effective instructional practices used in teaching biology, for example, are not the same as those used to teach physics. For this reason research on teaching specific science subjects is organized and presented in separate chapters, with the exception of elementary science teaching where the goal for that age group is the learning of general science concepts. That pedagogical practices in science education are viewed as discipline specific begs the question of whether practices in technology education could or should be viewed similarly. For example, what benefit might there be in researching distinct pedagogical practices associated with content (disciplines) organized around physical, informational, and biological technologies (ITEA, 1996); or perhaps as organized in the *Standards for Technological Literacy* (ITEA, 2000) by Energy and Power, Information and Communication, Transportation, Manufacturing, and Construction, and Agricultural and Related Biotechnology?

In addition to thematic organizers, further research structure was provided in the form of guidelines for asking and investigating questions regarding science education. Briefly, these guidelines specified that improving science teaching/learning worldwide must be the overall goal, that all research must be grounded in the real world of educational practice, that the profession as a whole must remain open to new research theories and methods, and that results must be presented in a manner that allows for practical interpretation by the various stakeholders, from teachers to policymakers. Directed by a thematic progression and based on a clear set of guidelines, the resulting 2007 *Handbook of Research on Science Education* (Abell & Lederman) presents to the profession a theoretically based, well articulated research agenda organized around five research priority categories as briefly summarized in Table 1 below.

Table 1 Summary of research foci within five science education research priority categories

Priority Category	**Summary of Research Focus**
Science Learning	Research to improve understandings regarding learner/teacher perspectives on science learning, the role of language and classroom discourse in science learning, recognizing interest is an important requisite for learning science and therefore a need to investigate linkages between attitude and motivation, and assessing the influence/impact of the instructional environment, both formal and informal, on the learning of science
Culture, Gender, and Society and Science Learning	Set within the overarching issue of context when learning science, priorities address recent research trends on the relationship between "context" and understanding learners in ways that specifically focus on the *learners'* gender, culture, and special needs
Science Teaching	Grounded in the perspective that the teaching of science is discipline specific, this category includes research that relates to the methods and strategies unique to the major science disciplines, with the one exception being that of elementary science teaching since it is general science and not typically discipline specific
Curriculum and Assessment in Science	Broad spectrum of curriculum and assessment research spanning topics from science literacy, inquiry, and the nature of science to program evaluation, and both large and small scale assessments of science learning
Science Teacher Education	Focus is on research that investigates the science teacher's learning, reflective of the recent ground swell of attention and new understandings related to teacher knowledge, pre/in-service professional development, the teacher learner, and the teacher researcher (as distinct from action research); particular attention given to content and pedagogical preparation issues, inclusive of practices necessary for integrative approaches to teach content from multiple fields

Constrained by chapter length limitations, this brevity of coverage does not do justice to the information offered through these categories of science education research. However, it provides the conceptual organization presented in the 2007 *Handbook* for research conducted on science education, as well as indications of possible avenues for research crossover within technology education. Specifically, the research addressed in the categories of Science Learning, Science Teaching, and Science Teacher Education hold particular relevance to the research gaps identified in technology education.

A COMMONS FOR TEACHING AND LEARNING RESEARCH

The *commons* is a centuries old concept referring to a resource, such as land, that is commonly owned and used by members of a community. Today the term seems equally applicable for envisioning a STEM education research collaboratory focused on the growing body of educational research questions, methods, and strategies used among these disciplines, and in particular for science and technology education considering their longstanding parallels in content and pedagogical practices. A model well suited for this is found in the PK-12/University *collaboratory* (Wells, 1999; Wells, Webb-Dempsey, & Khun-Van Zant, 2001) established through professional development schools that provides stakeholders the common ground necessary for *reformed education* (Wells, 2008). However, as previously discussed, technology education lacks an accepted assessment structure, and without that structure the extent to which such research can be used to establish technology education as a viable contributor to the core curriculum is limited. Paralleling science education, this issue could be addressed by similarly developing structures for assessing student learning in technology education. As presented in the NAEP 2009 science assessment framework (NAGP, 2008), student learning of content and practices in science education is assessed by correlating performance expectations as observed across each of the four science practices (Figure 2). Furthermore, to indicate the various ways of knowing and thinking that students should be able to demonstrate, each of the four practices is underpinned by a set of four cognitive demands: *knowing that* (declarative knowledge), *knowing how* (procedural knowledge), *knowing why* (schematic knowledge), and *knowing when and where to apply knowledge* (strategic knowledge). A student's ability to respond to the cognitive demands allows for assessment of expectations at the basic, proficient, and advanced levels with respect to learning both content and practices. The cognitive demands provide a mechanism for assessing knowledge gained along a continuum from declarative, to procedural, to schematic, and finally to strategic knowledge.

Figure 2.General Performance Expectations for Science Practices

Identifying Science Principles	Using Science Principles	Conducting Scientific Inquiry	Using Technological Design
Describe, measure, or classify observations	Explain observations of phenomena	Design and critique aspects of scientific investigations	Propose or critique solutions to problems given criteria and scientific constraints
State or recognize correct science principles	Predict observations of phenomena	Conduct science investigations using appropriate tools and techniques	Identify scientific tradeoffs in design decisions and choose among alternative solutions
Demonstrate relationships among closely related science principles	Propose, analyze, and evaluate alternative explanations or predictions	Identify patterns in data and/or relate patterns of data to theoretical models	Apply science principles or data to anticipate effects of technological design decisions
Demonstrate relationships among different representations of principles	Suggest examples of observations that illustrate a science principle	Use empirical evidence to validate or criticize conclusions about explanations and predictions	
← Communicate accurately and effectively →			

NAEP 2009 Science Framework (NAGB, 2008, p. 80)

Most educators are familiar with the concepts of declarative and procedural knowledge. Schematic and strategic knowledge are less familiar concepts, and need further explanation to articulate their potential for facilitating research on the pedagogical crossovers inherent within the design-based learning approaches used by both technology and science education.

RESEARCH ON DESIGN-BASED LEARNING

In science education, schematic knowledge refers to a student's ability to explain and predict natural phenomena, and to use reasoning in their evaluation of scientific claims regarding those phenomena. Strategic knowledge is the highest order learning stage among the cognitive demands and reflects the student's ability to transfer knowledge in solving novel tasks or problems. Knowledge transfer is an advanced thinking process that underpins practices used in technological design, scientific inquiry, and the integration of both. The capacity technological design has for assessing these higher order cognitive demands is explicitly stated in the NAEP 2009 Science Framework: "In terms of cognitive demand, both declarative knowledge (knowing that) and schematic knowledge (knowing why) come into play for the three components of Using Technological Design, as does strategic knowledge, (knowing when and where to apply knowledge)." (NAGP, 2008, p. 77). These are areas of cognitive demand integral to design-based learning and integrative practices in both technology and science education, and serve as the basis for replication and collaborations to research how students adapt prior science and/or technology knowledge to authentic, novel problem scenarios.

Replicating research in science education surrounding these parallels in cognitive demands is one approach for addressing the identified gaps in technology education research. National encouragement to build on such research in other fields as a means of assessing technological literacy came in a set of recommendations from the Committee on Assessing Technological Literacy in their 2006 publication *Tech Tally* (NAE, 2006), and specifically in Recommendation 7 calling for research on learning by funding studies that would draw from research in other disciplines such as "…learning in science and mathematics, spatial reasoning, design thinking, and problem solving" (p. 11). In recent years a growing number of technology education researchers have promoted design-based learning (DBL) and integrative practices as points of content/practice crossover with strong potential for establishing a teaching and learning research commons.

Lewis in 1999, building from his shifting beliefs regarding disciplinary border crossings (Lewis, 1996), broached the idea of conducting research on parallels in conceptual frameworks for teaching and learning held by technology education that would unite it with other school disciplines. Couched in a set of eight questions, he proposed points of research crossover that would help technology education achieve new paradigms for investigating teaching and learning. His idea of research along disciplinary borders crystallized in 2006 with specific attention to design and inquiry as conceptual parallels (Lewis, 2006). The use of design and inquiry in science, engineering, and technology education was shown to exhibit close resemblances in both processes and integration of content. Implications for accommodating border crossings through design and inquiry extends to the assessment of schematic and strategic cognitive demands in all three fields as a platform for investigating the commonalities of what students should know and be able to do.

Similarly, Petrina, Feng, and Kim (2008) echoed the potential for design and inquiry as crossover points based on the potential of design-based research to provide the experimental control necessary for assessing schematic knowledge, and for using cognitive ethnography to investigate distributed cognition, cognitive psychology, and human factors as could be revealed through assessment of strategic knowledge. The educational benefits of design-based learning were also presented by Daugherty and Mentzer (2008) as a method for promoting analogical reasoning; a cognitive tool fundamental to the design process (p. 9). Theoretically similar to cognitive apprenticeship, pattern recognition, schema, and concept or structure mapping, recognizing analogical reasoning as a cognitive outcome could help shape methods of assessing student learning (schematic and strategic knowledge) in a way that would inform design-based teaching practices in both science and technology education.

In each of the above arguments the goal for encouraging technology education to replicate the research conducted in other disciplines, and specifically science education, was to demonstrate the viability of student learning through the pedagogical practices of the field. Design-based learning is a pedagogical approach that presents core concepts in a way that concretely demonstrates to students the relevance and utility of content knowledge through an authentic context of need and application. The increasing attention by science education researchers for investigating the use of design-based approaches in the teaching of science is due in part to the inclusion of the Science and Technology Standard within the NSES (NRC, 1996). These standards are not to be confused with those of technology education, and are intended to "emphasize abilities associated with the process of design and fundamental understandings about the enterprise of science and its various linkages with technology" (p. 106). Specifically, the goal of Content Standard E: Science and Technology is for students to develop abilities of technological design ("identify and state a problem, design a solution – including a cost and risk-and-benefit analysis – implement a solution, and evaluate the solution", p. 107), and broaden their understandings about the relationship between technology and science (p. 135). However, it is important to recognize that Science Content Standard E impacts the science teacher's pedagogical practices by requiring them to incorporate, albeit to a limited extent (p. 192), the technological design process within their science courses, which in turn presents opportunities to research the impact on the teaching and learning process.

Recognizing the growing need for research on this impact, the editors of the *Journal of Research in Science Teaching* (Anderson & Hogan, 1999) called for papers reporting research on design in science education. In response to this and many similar requests, the capacity for improving student learning of science using this pedagogical approach has been repeatedly documented by a sizeable number of science education researchers (Barak, Wak, & Doppelt, 2000; Cajas, 2001; Crismond, 2001; Doppelt, 2004, 2006, 2007, 2009; Doppelt & Barak, 2002; Doppelt, Mehalic, & Schunn, 2005; Doppelt & Schunn, 2008; Fortus, et al., 2004, 2005; Seiler, Tobin, & Sokolic, 2001; Mehalic, Doppelt, & Schunn, 2005, 2008; Krajjick, et al., 1998; Roth, 2001; Roth, Tobin, & Simmerman, 2002). Learning core science and technology concepts in this way provides flexibility in using knowledge gained in novel contexts and enables students to use and/or reinforce prior learning of concepts in both science and technology classrooms. This natural incorporation of concepts from different disciplines mirrors the actual processes and approaches practicing scientists and technologists follow in solving or designing solutions to problems in the field (Bauer, 1992; McComas, 1996; Ledermann, 1998).

Traditionally, scientific inquiry has been presented as a linear sequence of events based on the scientific method, and as such did not mirror the actual practices of scientists in the field (Reiff, Harwood, & Phillipson, 2002). When solving real world problems in the field, scientists and technologists seamlessly transfer and draw on core knowledge from several different disciplines to arrive at solutions and answers. As practiced, authentic scientific inquiry is more fluid and conceptual, and when taught this way gives students a more pragmatic approach to testing their hypotheses (Fortus, et al., 2005; Harwood, 2004; Reiff, Harwood, & Phillipson, 2002).

Design-based learning combines both practical and theoretical knowledge in a blend of technological design and science inquiry. As a result, students are challenged to employ both vertical and horizontal thinking to synthesize information within learning environments that most closely resemble the authentic context of ill-structured design-based problems. In this way design-based learning creates the need for acquiring integrative understandings in a manner reflective of knowledge requirements in actual practice.

RESEARCH ON INTEGRATIVE PRACTICES

Discipline and content integration has been underscored in the educational reform and standards movements of both science and technology for more than a decade (NRC, 1996; NSTA, 1996; ITEA, 2000). Research in science education has recently suggested that technology is an appropriate vehicle for enhancing the integration of science with other subjects because it provides an authentic context for problem solving that assists students' transfer of knowledge while working toward solutions to real-world problems (Pang & Good, 2000). Research in cognitive science supports the belief that integrative practices using hands-on/minds-on methods creates a learning environment where students make connections in a manner that suits how the brain organizes information and constructs knowledge (Bruning, et al., 2004; Shoemaker, 1991). The brain continually seeks meaning within the patterns of information (pattern recognition) it receives and organizes that new knowledge by associating it with meaning and understanding (schema) developed through prior experiences (Cromwell, 1989). Regardless of the discipline or content, students will learn what their teachers teach them, and if the instructional approach used is one where content is fragmented and presented in isolation from other content then it will be learned that way (Humphreys, Post, & Ellis, 1981).

As previously mentioned, promoting knowledge transfer underpins integrative teaching practices (Sanders, 2006; Sanders & Wells, 2005; Wells, 2008), and supports the argument that such practices avoids the presentation of fragmented, isolated content typical of traditional methods (Lipson, Valencia, Wixson, & Peters,1993). Preparing today's students with tomorrow's skills begins by developing a knowledge base that reflects understandings of the relationships among disciplinary content required for solving complex problems involving interrelated variables (Benjamin, 1989).

To affect students' abilities to transform knowledge into personally useful strategies for learning new content and concepts requires that teaching be improved in a way that promotes integrative learning strategies. The need for such teaching abilities is emphasized in the National Science Education Standards (NRC, 1996) that state "Integrated and thematic approaches to curriculum can be powerful; however they require skill and understanding in their design and implementation" (p. 213). Though school subjects are still being taught using predominantly silo approaches, efforts continue in science education research to document the benefits of integrative approaches for improving student performance (Beane, 1995; Hartzler, 2000; Furger, 2002; Drake & Burns, 2004).

Empirical studies in science education investigating integrative methods have steadily increased over the past decade. Evidence of the positive impact integrative practices have on variables such as increased student achievement, improved interest, attitudes, and motivation, enhanced problem-solving abilities, and increases in content knowledge is being reported by a growing number of science education researchers (Vars, 1991; Greene, 1991; Westbrook, 1998; Isaacs & Gartzman, 1997). Though a considerable number of studies conducted in science education have begun to document the benefits of integrative approaches to science learning, the majority continue to do so by fostering students' conceptual understandings of science. In contrast, technological design as the signature pedagogy of technology education is an instructional strategy intended to make abstract concepts more concrete (ITEA, 2000). This pedagogical framework supports the integration of science (and other) content by intentionally coupling design-based learning to scientific inquiry with the expressed intent of facilitating knowledge transfer.

Though there is no disciplinary claim for integrative approaches, technology education is unique in that it affords the curricular flexibility and instructional environment necessary for facilitating design-based learning. The potential for demonstrating the value of technology education practices could be realized by analyzing how the curriculum it delivers promotes students' understanding of science and technology concepts. Clearly, by paralleling studies in science education, research conducted on integrative practices within the technology education classroom can document the effects of integration on students' conceptual development and identify just what the implementation of integrative practices really means at the classroom level.

RESEARCH ON TEACHER KNOWLEDGE

Design-based learning strategies employed in science or technology education serve as the contextual bridge for integrative learning of content in both fields. However, instructional design and classroom practices of this caliber will challenge even the most seasoned and knowledgeable educators. Successful incorporation of integrative practices is directly related to the breadth of teacher knowledge essential for this method of teaching. The scope of that knowledge was presented in Shulman's (1986) theoretical model where teacher knowledge was said to be comprised of seven categories: content knowledge, general pedagogical knowledge, pedagogical content knowledge, curricular knowledge, learner knowledge, educational context knowledge, and knowledge of educational ends. The majority of educators have not, nor are they currently being adequately prepared in these seven categories Shulman suggests, all of which are needed to integrate and teach multiple subject areas simultaneously (Warner, 2003; Zubrowski, 2002). To achieve this level of preparation calls for a process of both formal and informal preparation that develops an educator with knowledge of teaching well beyond that of the subject matter expert.

Research in the area of science teacher education has increased significantly in the past ten years. Specifically, research into the relationship between teacher knowledge and practice has been one of the main foci in the science education literature. Its significance to science education is clearly evident in the *Handbook of Research on Science Education* (2007) which devoted six chapters, an entire section, to teacher education issues. The significance of teacher knowledge (e.g. Shulman, 1986) in the teaching/learning process has been consistently and repeatedly supported through empirical research, and continues to substantiate the teacher as the single most important factor in facilitating student learning (Darling-Hammond, 2000, 2002; Darling-Hammond & Youngs, 2002; U.S. DOE, 2007; Committee on Science and Mathematics Teacher Preparation, 2001).

Though the evidence regarding the centrality of teacher quality in the educational process is overwhelming, science (and technology education) teacher preparation programs are still inadequate in developing teachers with the knowledge requisite of design-based and integrative teaching/learning. Beyond subject matter expertise, there remain many unanswered questions regarding what science/technology teachers should know and in what ways should they come to know it. The current research trends surrounding teacher knowledge are a necessary precursor to any substantive dialogue regarding relationships among teacher variables (teacher knowledge, beliefs, etc.) and integrative instructional practices.

The historical perseveration of the notion that increasing teachers' content knowledge improves instruction has not been supported (Fennema & Franke, 1992). Likewise, this was the conclusion Abell (2007) reached in her review of science teacher knowledge. Instead, research has shown that those teachers with more discipline specific teaching methods courses in which they acquire the necessary pedagogical content knowledge (PCK) are more successful in promoting student engagement and improving learning (Darling-Hammond, 2007; Malcom, 2008). Furthermore, these methods were not traditional didactic strategies, but those inclusive of hands-on/minds-on experiential learning integral to design-based learning approaches. However, Kennedy (1998) argued there was not yet sufficient evidence documenting the ways in which teacher knowledge actually contributes to teaching practices, and that further research was needed. Still, Wenglinsky (2002, 2000), using data from the National Assessment of Educational Progress (NAEP), found that student achievement goes up in both mathematics and science when teachers have specific professional development (pre/in-service) in hands-on teaching methods that target higher-order thinking skills.

Lehman (1994) and Stevens and Wenner (1996) researched perceptions held by pre/in-service teachers on integrative science and mathematics instruction. Their findings indicated that in-service teachers, in part due to their tradition-steeped, discipline-specific preparation, had negative attitudes toward integrative approaches, while pre-service teachers had a more positive perception. Collectively the research on instructional practices has not supported approaches that are either entirely “student-centered” or “teacher-centered.” What the research actually indicates is that student learning is best facilitated using a blend of strategies when and where they are most likely to have a positive impact under specified conditions (National Mathematics Advisory Panel, 2008). This speaks to one of the basic tenants of technology education, that “technology is a way to apply and integrate knowledge from many other subject areas” (ITEA, 2000, p. 6), which is accomplished through design-based learning and integrative practices. However, unlike our colleagues in science education, technology education lacks the research evidence necessary to substantiate the contribution of those practices for promoting student learning of knowledge and skills in core subjects at the PK-12 level. Obstacles to developing this evidence have been pointed out in prior reviews of technology education research (Lewis, 1996; Zuga, 2001; Hoepfl, 2002). Many, however, could be overcome through a *teaching and learning research commons* established among the STEM disciplines where a shared body of research questions, designs, methods, instruments, and strategies is used to coordinate research collaborations along points of content and pedagogical crossovers.

SUMMARY

Science education has been synthesizing their research on teaching and learning since the late 1920s, generating a sizeable number of reviews and summaries published through sponsorship by various professional organizations.

It was not until 1994 however, that a significant compilation of science education research conducted over a broad period of time was synthesized into a single *Handbook of Research on Science Teaching and Learning* (Gabel, 1994). The most recent effort to compile science education research was contained in the 2007 *Handbook of Research on Science Education* (Abell & Lederman, 2007), which was distinct from earlier handbooks in that it included international scholars and was intentionally designed to be comprehensive in its coverage of research. The overarching structure of the science education discipline was presented in the 2007 *Handbook* and organized around five categories of research: Science Learning; Culture, Gender, and Society and Science Learning; Science Teaching; Curriculum Assessment; and Science Teacher Education. The topics addressed within these categories represent the research priorities and future research directions for the field. Though the 2007 *Handbook of Research on Science Education* contains many areas of research relevant to technology education, space constraints for this yearbook chapter allowed for discussion of only three research categories: Science Learning, Science Teaching, and Science Teacher Knowledge. These categories provided the structure for selecting, reviewing, and synthesizing the literature surrounding science education research that holds particular promise for informing research in technology education used in preparing this chapter.

The chapter began by establishing the existence of a relationship between the current framework that organizes research in the science education discipline and the Science Framework (NAGB, 2008) used for the 2009 National Assessment of Education Progress. This relationship provides the foundation to guide the conduct of empirical research science education needs to demonstrate its impact on student learning of science at the PK-12 level. Specifically, it affords science education a mechanism for researchers to investigate and document how well the profession is achieving the goals of science education. Technology education has in place many of the same standards and benchmark structures used in science education, but lacks the national assessment structure necessary to connect research with PK-12 teaching/learning impact.

The science education research framework was used to align known gaps in technology education research with analogous research topics addressed within the categories of Science Learning, Teaching, and Teacher Education. These alignments served as the platform for discussing points of pedagogical crossover revealed within design-based learning and integrative practices employed by both science and technology education. There are clear implications for accommodating border crossings through design-based learning that particularly lend themselves to investigations of the schematic and strategic cognitive demands on student learning in both fields. These points of crossover are avenues where those in technology education might replicate or collaborate on previously conducted research in science education as a means for demonstrating the viability of their own pedagogical practices to promote student learning of core content. Empirical studies in science education investigating integrative methods have also provided evidence of the positive impact such practices have on many of the variables associated with student learning. For example, the effective implementation of integrative instruction has been shown to assist students in understanding the relationships among disciplinary content and to transfer prior knowledge in solving complex real-world problems. Technology education is unique in that it affords an authentic context for problem solving that assists students' transfer of knowledge while working toward solutions to authentic problems. Technology education would clearly benefit from paralleling studies in science education to demonstrate the value of its own practices for promoting students' conceptual development. Doing so would also present the opportunity to investigate the types of teacher knowledge required for integrative practices.

The significance of teacher knowledge in the teaching/learning process has been consistently and repeatedly supported through empirical research. This research continues to confirm the centrality of the teacher and recognizing that the teacher remains the single most important factor in facilitating student learning. Content knowledge alone has been found to be insufficient for teaching even a single subject, let alone design-based learning using integrative practices. The ability of the educator to help others learn is directly linked to the level and breadth of teacher knowledge they possess. The seven categories of teacher knowledge proposed in Shulman's (1986) theoretical model of teacher knowledge were recognized by the science education community as useful for structuring science teacher preparation programs. As a result these programs will be well positioned for developing educators with the range of teacher knowledge needed to employ not only science inquiry pedagogy, but design-based and integrative practices as well. It is conceivable then that this approach to the preparation of science teachers may better prepare them to implement technology and design-based learning methods than technology education teachers.

The challenges faced by the technology education profession in presenting a body of research to empirically demonstrate the contributions of its pedagogical practices to the educational enterprise have been pointed out multiple times over the years (McCrory, Foster, Hoepfl, Lewis, Waetjen, Zuga, etc.). In fact Zuga (1994) made this challenge explicit in her statement that research was needed to "demonstrate the inherent value of technology education" (p. 64), a point echoed by Lewis a few years later who stated "To take its place squarely in school curricula, technology education must establish itself not only in its own right, but crucially in relation to other subjects" (1999, p. 49). In contrast, science education has effectively used research to establish the credibility of its pedagogical practices for promoting student learning. Aligning national science education standards with national science assessment standards provides a framework and inherent strategy for investigating linkages between student learning and teacher practice. Design-based learning, as an instructional approach employed by both technology and science educators, presents a research focus of mutual interest. Moreover, because this teaching approach necessitates integrative practices and unique teacher knowledge, it presents these as additional areas of common research. With established lines of research in science education currently addressing these topics, researchers in technology education have the opportunity to replicate or collaborate on research that links practice with student learning. In so doing, they will address those key research gaps identified in technology education and generate the empirical evidence needed to demonstrate the value of its pedagogical practices and its legitimacy as a school subject.

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