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Pedagogical Content Knowledge and Technology Teacher Education: Issues for thought

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Introduction

Instead of focusing on what to teach students, Pedagogical Content Knowledge focuses on the strategies employed in teaching; those strategies that bring about the best learning experience for every learner. PCK involves knowing how to take advantage of different teaching approaches that make a learning experience most suitable for the learners. This includes being flexible and adjusting instruction to account for various learning styles, abilities and interests. Knowing how to best teach a concept so that the learners will receive the best learning experience speaks to the essence of PCK. The different teaching approaches employed will vary from teacher to teacher and from differing contexts but invariably will revolve around similar principles for each approach.

The notion of pedagogical content knowledge was first introduced to the field of education by Lee Shulman in 1986 and a group of research colleagues collaborating on the *Knowledge Growth in Teaching (KGT)* project. The focus of the project was to study a broader perspective model for understanding teaching and learning (Shulman & Grossman, 1988). The KGT project studied how novice teachers gained new understandings of their content, and how these new understandings interacted with their teaching. The researchers of the KGT project described pedagogical content knowledge as the knowledge of three knowledge bases coming together to inform teacher practice: subject matter knowledge, pedagogical knowledge, and knowledge of context. Subject matter content knowledge is described as knowledge that is unique to teachers and separates, for example, an engineering and technology teacher from an engineer. Along the same lines, Cochran, King, and DeRuiter (1991) differentiated between a teacher and a content specialist in the following manner:

> Teachers differ from biologists, historians, writers, or educational researchers, not necessarily in the quality or quantity of their subject matter knowledge, but in how that knowledge is organized and used. For example, experienced science teachers' knowledge of science is structured from a teaching perspective and is used as a basis for helping students to understand specific concepts. A scientist's knowledge, on the other hand, is structured from a research perspective and is used as a basis for the construction of new knowledge in the field (p. 5).

Geddis (1993) described pedagogical content knowledge (PCK) as a set of attributes that helped someone transfer the knowledge of content to others. According to Shulman it includes "most useful forms of representation of these ideas, the most powerful analogies, illustrations, examples, explanations, and demonstrations-in a word, the ways of representing and formulating the subject that make it comprehensible to others" (Shulman, 1987, p. 9).

In addition, Shulman (1987) suggests that PCK is made up of the attributes a teacher possess that help her/him guide students towards an understanding of specific content such as engineering in a manner that is meaningful. Shulman argued that PCK included "an understanding of how particular topics, problems, or issues are organized, presented, and adapted to the diverse interests and abilities of learners, and presented for instruction" (1987, p. 8). In light of what engineering and technology education teachers should know and be able to do, Shulman argued that pedagogical content knowledge was the best knowledge base of teaching and suggests;

> The key to distinguishing the knowledge base of teaching lies at the intersection of content and pedagogy, in the capacity of a teacher to transform the content knowledge he or she possesses into forms that are pedagogically powerful and yet adaptive to the variations in ability and background presented by the students (p. 15).

Therefore, the intersection of engineering science, i.e., knowledge of the scientific knowledge needed to engage in the analytical aspects of design, knowledge of engineering design, with teaching in the technology education classroom will wholly depend on the ability of teacher educators and pre-service teachers to transform this knowledge into adaptive instruction, with which students can engage. Figure 1 helps to capture the complex relationship between content knowledge, knowledge of teaching, context, and their interaction in an instructional setting.

Figure 1. *Infusion of Engineering Knowledge, Pedagogy and Context in Technology Education Instruction*

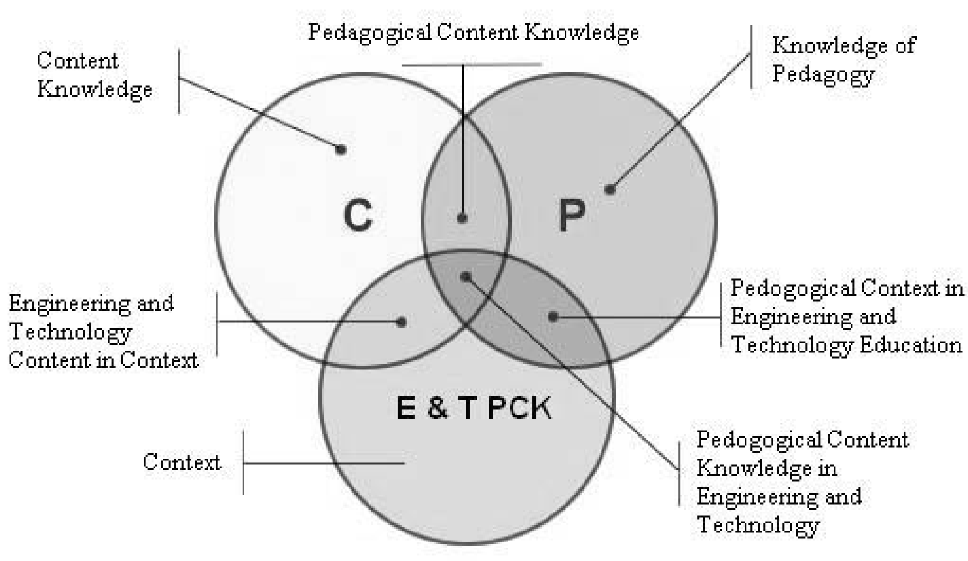

Figure 1 helps to conceptualize the complex relationship between a teachers content knowledge in technology education in addition to knowledge required to infuse engineering concepts into classroom instruction. This knowledge combined with pre-service teachers general knowledge of pedagogy helps to contribute to a specialized form of pedagogical knowledge in engineering and technology. In addition, the specialized knowledge of engineering and technology is often highly contextualized in the form of authentic application to design problems that are context bound. The continued interest in PCK as an epistemological perspective in the preparation of pre-service engineering and technology teachers and as a knowledge base for infusing engineering principles, content, and method in the study of technology has yielded a desperate need for our field to produce a conceptual framework and taxonomy for the infusion of engineering upon which future PCK studies in engineering and technology education can be based.

How the T&E in STEM Impacts Technology Education?

With the high-tech boom of the 1990's, the bust of 2000-01, and the ensuing anxieties about competitiveness and national security, K-12 Science, Technology, Engineering and Mathematics (STEM) education has commanded the attention of people far beyond the community of educators typically involved in the field. Policy-makers, industry leaders, and thoughtful leaders in the media have registered concerns and volunteered solutions regarding apparent problems with how science and mathematics are taught and learned and how technology figures as both a feature of these topics and a downstream result of their inculcation. All the while, engineering and technology has largely remained a shadowy presence in discussions about the K-12 STEM education, a spectral "T&E" quietly inserted among its more concrete complements, yielding, if nothing else, an acronym that lends itself nicely to speech and writing. In addition, the technology education community must be cautious in assuming that the "T" in STEM refers to technology education. General interpreted in the educational and professional community could reserve the “T” in STEM for information science and computing technology and not technology education. In K-12 schools this could mean educational technology.

Recent arguments in favor of defining and implementing a more substantial role for engineering in K-12 STEM education are many and strong. Starting with the most general, K-12 education, as a democratic institution, should provide meaningful preparation for its graduates, in all their representative diversity, to participate fully in the opportunities available to them in society. Among the ways that people participate in society—at home, at work, in communities, or any other context—almost every experience is shaped by a product or environment that results from engineering. Buildings, clothes, cars, clean water, indoor climate control, personal technologies, and nearly everything else people encounter in daily life comes from engineering. An education system that treats this area of activity obliquely, if at all, is failing to prepare students for the world they will enter upon completing their studies. Understanding first that the world they inhabit is engineered and second that the engineered world takes the shape it does through human choice and activity, areas in which they themselves can participate, is a fundamental precondition for full participation in twenty-first century life.

Engineering is an important national resource in efforts to keep industrial countries competitive in a knowledge- and technology-driven global economy and safe in an uncertain geopolitical climate (National Research Council, 2006). Technological innovations result from the work of people trained in engineering and technology fields. Educated across disparate areas of science and mathematics, these people translate their understanding of fundamental science and mathematics into usable objects and applications that improve our lives, create new jobs and industries, and extend the frontiers of human possibility. They also play a fundamental role in national security strategies, combating threats to a country's citizenry through research and development of technologies that can neutralize threats to civilian and military populations. Engineering conveys practical, classroom benefits for educators and students, as well. A way to bring to life sometimes abstract, difficult topics in math and science, engineering can make the classroom exciting and relevant to lived experience. Research shows the integrative, applied nature of engineering can enhance student learning, boosting test scores and helping schools meet standards-driven education requirements (Baker 2005). The collaborative, socially beneficial aspects of engineering have also been shown to appeal to students whom the field has traditionally failed to engage, including females and under-represented minorities (Guertin and Rufo 2004, Wiest 2004).

Learning from taxonomies and conceptual frameworks

Two explicit taxonomies are available in the science education literature and a framework in the technology education literature that can help guide the field of engineering and technology education in understanding the PCK required to deliver meaningful engineering content (McCormick & Yager, 1989; Neale & Smith, 1989, Lewis & Zuga, 2005). Neale and Smith (1989) constructed a configurations checklist, or taxonomy, for evaluating teaching performance. The features of this checklist included: lesson segments, content, teacher role, student role, activities/materials, and management. The checklist pertained to conceptual change in teaching of science. A teaching performance was rated for each feature of the checklist in terms of high vs. low implementation. McCormick and Yager's (1989) taxonomy of teaching and learning science incorporated five categories or domains of science education. The taxonomy was designed to help students become scientifically and technologically literate. The five hierarchical domains were organized by importance: (a) knowing and understanding (scientific information),

(b) exploring and discovering (scientific processes), (c) imagining and creating (creative), (d) feeling and valuing (attitudinal), and (e) using and applying (application and connections).

The taxonomy listed what students could do or learn in each domain. McCormick and Yager (1989) asserted that too often, science education limited students to the first two domains that primarily focused on the processes and products of science. They stated that the other three domains needed to be included more often in science instruction due to the increased focus on science, technology, and societal issues.

In technology education, Lewis and Zuga (2005) in their publication titled *A Conceptual Framework of Ideas and Issues in Technology Education.* Zuga and Lewis take up the question of domain knowledge and teacher competence required for technology teachers to teach engineering design. The questions raised in this well constructed framework have direct implications and relationship to PCK. For example, Lewis and Zuga state that design in technology education often shows itself in the form of a space to be spanned by a bridge, a tall tower to be built, or a structure that will bear load. Students compete to see which individual or group has built the tallest tower, or has constructed the longest bridge, or has gotten its structure to bear the most weight. Often the teaching episode ends when a winner is identified, without students' gaining understanding of the reasons behind the success or failure of their attempts. That kind of rote approach to design Lewis and Zuga emphasize, misrepresents and grossly simplifies the task of the engineer, and perhaps more critically, it inhibits student creative performance, a critical aspect of which is possession of requisite content knowledge (p.64). The authors go on to explain the various conditions that in turn can help define the content knowledge required to effectively teach engineering design if either from a *process* perspective or a *design challenge solution* grounded within a particular domain.

Lewis and Zuga also take up the notion of teacher competence. The authors question the amount of domain specific knowledge necessary to effectively teach with a domain and further argue that technology teachers also posses some agreed upon competence level in mathematics and science. These discussions raise serious questions regarding the redesigning of technology education teacher preparation programs to prepare teachers to infuse engineering concepts and design into the technology education classroom and adequately represent engineering content in a valid and reliable manner.

The organization of domains of grade-appropriate knowledge for the infusion of engineering content, principles, and practice in the technology education classroom within a taxonomy hierarchy could help technology teacher educators and pre-service teachers. The taxonomy of hierarchical domains in the study of engineering applied to the K-12 classroom as opposed to the practice of engineering, could serve as a catalyst in helping teachers negotiate the inherent overlap between general technological content for the study of technology, STEM content, specific engineering science, principles, and design, and pedagogical knowledge. The development of an explicit teaching and learning taxonomy for the study of engineering and technology in a K-12 setting would alleviate the diffusion of curriculum claiming to teach engineering while providing clear guidance for curriculum development. A well understood taxonomy would also facilitate meaningful communication and cooperation between the technology education and engineering communities. Furthermore, a taxonomy to reflect engineering content for K-12 education could be overlaid on to science, mathematics and technology taxonomies to assist teachers in building knowledge relationship maps that could inform instruction towards more meaningful learning. Conversation and efforts could turn to more significant work on *how to teach* rather than expend resources on *what to teach*. A well designed taxonomy that can guide the K-12 engineering and technology community would set the stage for pedagogically powerful and yet adaptive ways that teachers could respond to the variation in ability and background presented by the students in engineering and technology classrooms; equipped with such a tool, powerful teaching could ensue.

Critical considerations for PCK and the training for pre-service technology teachers

Science education and indeed PCK research has important messages for the teaching and learning of technology education and the infusion of engineering concepts into the curriculum, but I wonder if the focus is not too much on advancement, rather than application, of generic educational theories. Commenting on criteria used for evaluation of teaching in the 1980s, Shulman (1986) asked “Where did the subject matter go? What happened to the content?” Of course we should attempt to advance educational theory, in the same way that any other discipline does “pure research”. But surely advances in theory of a discipline have only one purpose: to reflect back on, and improve, the practice of that discipline. Is the time ripe to think through what we now know about student learning, in conjunction with analysis of what it means to understand particular concepts in technology and engineering, to generate useful pedagogical practices specifically tailored for each concept and then to assess through research, the effectiveness of these practices? This would correspond with the notion of “applied research” in the technology teacher preparation field.

A clue to the future may be represented in the following thoughts from Fensham & Kass, 1988; there are two primary and interacting sources of events in instruction in technology education that can lead to inconsistency or discrepancy for its learners. The first is the science or the nature of the technology itself. The second is the teaching of the technology under study and its varied forms of application, context and pure knowledge of the content. The interaction between these two sources is obvious, but it is often ignored in the education of technology teachers.

Perhaps a productive path for us to travel is to examine more critically the concept of PCK and what it means or could mean to the preparation of future technology education teachers. In addition, examining the notion of PCK can inform our understanding of what is required to teach and infuse engineering concepts in the technology education classroom. While *content knowledge* refers to one's understanding of the subject matter, and *pedagogical knowledge* refers to one's understanding of teaching and learning processes independent of subject matter, *pedagogical content knowledge* refers to knowledge about the teaching and learning of particular subject matter, taking into account its particular learning demands. The rationale for doing this is appropriately suggested by Geddis (1993):

> The outstanding teacher is not simply a 'teacher', but rather a 'history teacher', a 'chemistry teacher', or an 'English teacher'. While in some sense there are generic teaching skills, many of the pedagogical skills of the outstanding teacher are content-specific. Beginning teachers need to learn not just 'how to teach', but rather 'how to teach electricity', how to teach world history', or 'how to teach fractions' (p. 675).

Or, 'how to teach statics', or 'how to teach material science', or 'how to teach computer aided design". Obviously the demands of learning about statics are different from the demands of learning about material properties. Good teachers are able to carefully analyze the various sorts of content-specific demands in each of these areas related to teaching engineering design.

Each technology teacher has a unique knowledge of specific domains spanning multiple content areas identified the study of technology (ITEA, 2000). As technology teacher educators, we can never hope to transmit to the pre-service technology teacher a duplicate of this knowledge. Our hope for the prospective technology teacher is to re-package and re-present her/his knowledge in such a way that gives the students some hope of achieving the understandings that we hope for. The re-packaging task will depend upon the nature of the subject matter. So we in teacher preparation have to come to know the subject matter in both engineering and technology, not only for itself, but also in terms of its teachability and learnability. This task has been conceptualized by Shulman, 1986 as “transformation of subject-matter knowledge into forms accessible to the students”. The implications for this in terms of coming to know about engineering principles as well as principles in technology and their relationship to science and mathematics will require the technology education teacher preparation program to branch out well beyond the traditional bounds of technology education to embrace and collaborated with our STEM partners and share in the preparation of future technology education teachers. Geddis (1993) informs us that “in order to be able to transform subject matter content knowledge into a form accessible to students, teachers need to know a multitude of particular things about the content that are relevant to its teachability” (p. 676). Developing ways to do this is indeed the creation of new knowledge of a type that characterizes the good teacher and is part of her/his professional skill. The requirement for teachers to invent this new integrated knowledge must be recognized by the technology teacher preparation community. The highest levels of teaching ability required by technology teachers in an environment of ever expanding technological frontiers will demand more than just a cursorily knowledge of technological and engineering concepts.

PCK and the hall of mirrors

The use of engineering content as the basis for technology education has both proponents and opponents; however can we gain an effective understanding of what it takes to teach within these two content domains from a PCK perspective? The discussion of engineering and technology content interacts with the following competing issues in the classroom:

- High stakes testing (Williamson, Ndahi, Waters & Nelson, 2005)
- Adequacy of engineering design (Dearing and Daugherty, 2004; Pearson, 2004)
- Alignment with standards (Genalo and Ogren, 2005; Koehler, Giblin, Moss, Faraclas, and Kazerounian, 2006)
- Abilities of engineers to teach (High, Beller & Redmond, 2006)
- University commitment (Ybarra, Klenk & Kelly, 2006)
- Teacher readiness (Cunningham, Lachapelle, and Lindgren-Streicher, 2006)
- Technology literacy needs versus engineering education (Loveland, 2006)

One of the roadblocks to increasing attention to teaching engineering and technology content at the K-12 level is the accountability systems that have effectively forced many schools to gear their curriculum to support student success on high stakes achievement tests used for accountability. This approach tends to stifle innovation in curriculum development and limit the time available in the school day/year for additional content. Williamson, Ndahi, Waters and Nelson, (2005) have worked to overcome these issues through the approach of providing both the content and presentation of engineering-related material in the K-12 system using engineering graduate students. This relieves the pressure on the K-12 faculty to learn new content and in essence lessen the PCK load on teacher. In technology education, this same emphasis on accountability may actually assist in the introduction of engineering concepts into the curricula as outlined in the Standards for Technological Literacy: Content for the Study of Technology (STL) (ITEA 2000), which contain a significant amount of engineering content. Additionally, engineering content can be presented in a manner consistent with not only technology standards but also math and science standards (Genalo and Ogren 2005). A significant unanswered question is how and to what level of knowledge across each of these interacting subjects does a teacher need to know or master to effectively achieve a level PCK in order to teach STEM in an integrated manner?

Building blocks of PCK in engineering and engineering design

The connections between engineering design and technology education standards have been discussed by technology educators and engineering professionals (Dearing and Daugherty 2004; Pearson 2004). Pearson indicates that “Design in technology education most closely allies with engineering design.” He then describes how informed design can be used to create a constructivist pedagogy centered on engineering design. Dearing and Daugherty explore the connection between technology education and engineering design through a process of identifying core design concepts that align with the technology standards. Their goal was to investigate the possibility of providing technology education with a basis that could be used to increase technological literacy for all students while also supporting the recent push to have technology education support pre-engineering programs for students. Through a process of rating concepts by teams of technology teachers, technology teacher educators, and engineering educators, a core set of concepts was picked through consensus ratings –a promising step towards the alignment of engineering design and technology education.

In a recent study by High, Beller and Redmond, 2006 the authors were successful in demonstrating the value of having engineers involved with the pre-service preparation of education majors. The study showed that the use of an engineering faculty member in a course designed to help K-12 teachers teach both science and engineering topics could lead to greater confidence on the part of the pre-service students in teaching science and engineering than a control group that did not have an engineering faculty member involved in the class instruction (High, Beller & Redmond, 2006).

For engineering faculty, a key question is: what priority is given to K-12 activities by engineering programs? Despite the public calls for this type of outreach by the engineering profession, participation in K-12 activities is not always valued by administrators (Ybarra, Klenk & Kelly, 2006). Faculty wanting to develop curricular materials provides professional development, etc., for K-12 will often be putting at risk career advancement until the culture of engineering programs fully accepts the role of cooperating beyond the traditional boundaries of research and undergraduate education.

The question of the preparedness of technology educators to present engineering concepts must also be addressed at the in-service level. There are many teachers who are currently under-prepared to properly teach engineering concepts and lack the fundamental components of the PCK required. Most technology educators have not been trained as engineers. Therefore, engineering programs need to professional development for these teachers, as being done at Tufts University (Cyr, Doherty & Shanbhag, 2006). Looking at this issue from the point of view of engineering, there can be concerns that the needs of programs producing technology teachers may require materials that engineering would consider to be too elementary to be in engineering curricula but required for meeting the ITEA STL standards. For example, in the program described by Loveland, 2006 the topics of web page design, production, and assessment, along with desktop publishing are included. These topics would often not be representative of an engineering content for a curriculum.

Implications for Technology Teacher Education

The general PCK taxonomy and the taxonomy of PCK attributes provide a relatively comprehensive categorization scheme for future studies of PCK development in teacher education. The continued interest in PCK as an epistemological category and as a knowledge base for technology teacher preparation has produced a need for a conceptual framework upon which future PCK studies can be based. The taxonomies and frameworks presented in this paper provide some insight into where additional thought is necessary in technology education as the field grapples with the infusion of engineering content into the curriculum. First, the general taxonomy of PCK will allow researchers and teacher education programs to more accurately identify and address distinctions among knowledge bases of various educational disciplines, technological subjects, and engineering topics. In other words, it will provide a classification scheme for implementing unique instructional methods in the technology education classroom. Second, the taxonomy of PCK attributes will enable researchers studying knowledge development in teachers and teacher education programs to identify and characterize different attributes of technology teaching that infuse engineering content domain knowledge. In addition, this paper recognizes the relative importance that researchers and educators have given to the different components of PCK. The varied types of organizational frameworks and taxonomies emerging in technology education will serve to organize and integrate research efforts centered on PCK.

The use of taxonomies and frameworks as a foundation for future research will also provide a model for technology teacher preparation. For example, technology education teacher preparation programs could focus on developing topic-specific PCK in prospective teachers. Many pre-service technology teachers know their content well, but they have not learned how to transform or translate that knowledge into meaningful units for instruction. By focusing on topic-specific examples, laboratories, and demonstrations, pre-service technology teachers can focus and develop specific strategies. What is necessary is the effective use of exemplary models of technology teaching within topics that can later be transferred to another topic or domain. They can then apply these strategies to other topics and domains based upon their content backgrounds.

Directly or indirectly, teacher education programs will benefit from further PCK research. One obvious area of future research would be to focus on identifying and classifying the various types of PCK employed in the technology education classroom that appropriately infuses engineering design and concepts into instruction. This would allow both teachers and teacher educators to more easily identify PCK development in themselves and their students. The ability to track PCK development will enable technology education teacher preparation programs to modify their classes and curricula appropriately. It is our hope that these taxonomies will provide a foundation for future research and further discussion concerning the preparation of highly qualified technology education teachers.

Finally, the identification and classification of the various types of PCK does not exclude the consideration of technological content areas that combine one or more of the traditional disciplines (i.e. manufacturing, transportation, construction, etc...). Once researchers are able to identify various components of PCK in the traditional technological fields, then they can begin to examine how teachers contend with these "new" areas of technology education that incorporate STEM components into their instruction. Disciplines such as biotechnology and bioengineering are rapidly becoming an integrated portion of the new science and technology curriculum (AAAS, 1993; NRC, 1996). It is vital that we, as educators, develop an understanding about how to teach these new integrated subjects in a manner that reflects the knowledge of today’s science, technology and engineering in contrast the traditional discipline-bound courses.

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