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Session III: Research

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Abstract

What are the characteristics of exemplary teaching practice in technology and engineering education? This presentation will present an overview of the literature on exemplary teaching practices within subjects that emphasize project, problem, and inquiry-based learning, with a specific emphasis on linking teaching strategies to desired educational goals and student learning outcomes. Examples are drawn from across multiple disciplinary fields, particularly science, with suggestions for how these can be used in the technology and engineering classroom. The implications for technology teacher education will be addressed.

The Search for Exemplary Practice

Identifying Best Practices

The search for teachers who display exemplary instructional practices is something of a holy grail for teacher educators. More to the point, within technology and engineering (T&E) education we seek to identify those individuals who can serve as role models for our students, and whose teaching strategies can be distilled into sets of “best practices” for others to emulate. All of us can identify teachers from our own educational pasts who had the most positive impacts on our lives; many of us can point to technology teachers who were instrumental in shaping our own career paths. But how do we identify these influential and expert teachers, beyond just knowing one when we see one?

As Leinhardt (1990) summarized, the most commonly-used method is to seek nominations from others familiar with a teacher’s work, or in some cases to look at relative student outcomes on assessments. However, “nominations are often made based on characteristics that are important in the global view of teaching (i.e., a cooperative, enthusiastic, willing worker) rather than other important but more narrow characteristics (i.e., pedagogical subject matter knowledge)” (p. 19). Identifying exemplary teachers via nomination processes can be made more rigorous by gaining multiple nominations and by looking to other measures, such as the quality of teaching materials used or student successes in competitions or on standardized tests. In order to conduct a closer analysis of

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[1] Author’s note: A version of this paper will be published in the forthcoming book: Hoepfl, M. (Ed.). (in press). *Exemplary Teaching Practice in Technology & Engineering Education: CTETE 62nd Yearbook.*

best practices, however, we must explore strategies for uncovering what Leinhardt called the "craft knowledge" of teaching:

> Indeed, the very metaphor of craft knowledge evokes the guild model of hierarchy in skill, with the master modeling and passing on to the apprentice the historical art. It seems appropriate that we should seek the knowledge of the expert or, at a minimum, the reasonably successful and experienced practitioner. (Leinhardt, 1990, p. 19).

Hassard (2005) provided an even more poetic phrase to describe good teaching, which he called "professional artistry," in which you can "witness [the teacher's] imagination and creativity at play unfolding in the classroom" (p. 5). Generally speaking, nearly all accounts of excellent teaching address some aspect of what might be termed affective attributes of teachers. For example, Alsop (2005) stated "it has been widely acknowledged that pedagogical practices are inextricably tied to emotions" (p. 146), where negative emotions can overshadow efforts to structure learning in the classroom, and conversely teacher enthusiasm and confidence can serve as motivators that yield positive outcomes for students. "In research and practice the interaction of affect and cognition is largely understated. Affect is, more often than not, marginalized. In exemplary science teaching I suggest—quite simply—that it shouldn't be" (Alsop, 2005, p. 147). From this view, teaching practices refer not just to the instructional techniques used but also to the "personal dynamics between teachers and students and the interactions among students and assessments, educational technologies, laboratories, and myriad other teaching strategies" (Bybee, 2013, p. 6).

On Beyond Anecdote: Analyzing Best Practices

The forthcoming 62nd CTETE Yearbook features eight case studies of exemplary T&E teachers at the elementary, middle school, and high school levels. These are descriptive looks at the kinds of philosophies, strategies, and approaches these teachers employ. Although I believe this volume will make a positive contribution, to delve deeply into the characteristics of exemplary teaching practice more systematic and rigorous analyses that employ multiple data sources are needed (Capps & Crawford, 2013). Highlighted in this section of this paper are examples of studies that have attempted to do just that. Some of the key findings from these various studies are reported later in this document.

A recent study by Rose, Shumway, Carter, and Brown (2015) used a modified Delphi study to identify the basic competencies associated with excellence in T&E teaching that would be desired among pre-service T&E teacher education program graduates. They acknowledged that excellence "requires an interrelated set of skills, knowledge, and dispositions" (p. 17). The research team started with characteristics drawn from the Interstate Teacher Assessment and Support Consortium (InTASC) *Model Core Teaching Standards* (Council of Chief State School Officers, 2013), among other sources. As the authors of this study noted, resources such as state and national standards, evaluation systems like the National Board for Professional Teaching Standards, and the scholarly literature contain comprehensive lists of attributes of successful teachers, which comprise the "integrated, complex set of knowledge and skills known as Pedagogical Content Knowledge (PCK) (Rose et al., 2015, p. 3).

An interesting look at exemplary teaching in science education was undertaken by Alsop, Bencze, and Pedretti (2005), who edited a volume containing ten accounts of teaching written by K-12 science teachers accompanied by follow-on qualitative analyses of these accounts to elucidate the effective strategies described. The authors of the analytical chapters were tasked with "immersing themselves" in the accounts provided and with pulling out "a series of defining features to form the basis of recommendations for future practice" (Alsop, Bencze, & Pedretti, 2005, p. 93)

Tobin and Fraser (1987) described a study they conducted to assess exemplary teaching in science and mathematics in Australia. They relied on a nomination process to identify 20 exemplary teachers in Western Australia. Eleven research teams, each consisting of one or two researchers, conducted case studies of all of these teachers. Data were collected via direct observations of at least eight lessons in the classroom settings; via interviews with teachers and students; and through examination of curriculum materials, tests, and examples of student work. The work of these exemplary teachers was in each case contrasted with "comparison" teachers at each school (p. 25).

Capps and Crawford (2013) sought to examine the extent to which science teachers were actually implementing inquiry learning in their classrooms, in contrast to what the teachers stated they were doing. They used written descriptions of lessons, observations in the classroom, and interviews to characterize the targeted science teachers' instructional practice. Teachers were asked to provide descriptions of what they felt was "an exemplary, inquiry-based lesson they taught in the last two years" and semi-structured interviews with a subset of the teachers were conducted to "corroborate our interpretations and gain a greater understanding of the nature of their instructional practice" (Capps & Crawford, 2013, p. 504).

Best Practices in Context

Use of national and state standards to frame teaching practice has become an accepted and expected part of the educational process in the United States and elsewhere. Although the role of standards is not universally praised, nevertheless many would maintain that "standards have been found to drive innovation in education and can engender the implementation of assessments, teacher training, curriculum, and textbooks….[and are] necessary for transforming the ideas offered by subjects such as engineering into effective and relevant instructional practices" (Carr, Bennett, & Strobel, 2012, p. 542). These relationships are illustrated in Figures 1 and 2.

Although standards provide essential frameworks within which subject-area education can be viewed and developed, it's important to note that as they are translated across the levels depicted in Figures 1 and 2 there can be some "errors in translation." Banks and Barlex (2014), for example, contrasted the *specified*, the *enacted,* and the *experienced* curriculum, which align, respectively, with *standards/curriculum, instructional practices,* and *students* in my model. Similarly, Tobin and Fraser (1987) talked about the "intended, implemented, perceived, and achieved curriculum" (p. 30). "It is very difficult to impose a curriculum on teachers, be it from central government or from within a school management structure" (Banks & Barlex, 2014, p. 33), in part because of the translational errors that occur from one level to another, but also because teachers may lack the desire or the capability to enact the specified curriculum. Capps and Crawford, in their comparison of what teachers *felt* they were doing (implementing exemplary inquiry learning) and what the researchers observed, found that "even some of the best teachers…struggle to enact reform-based teaching" (2013, p. 498) in science.

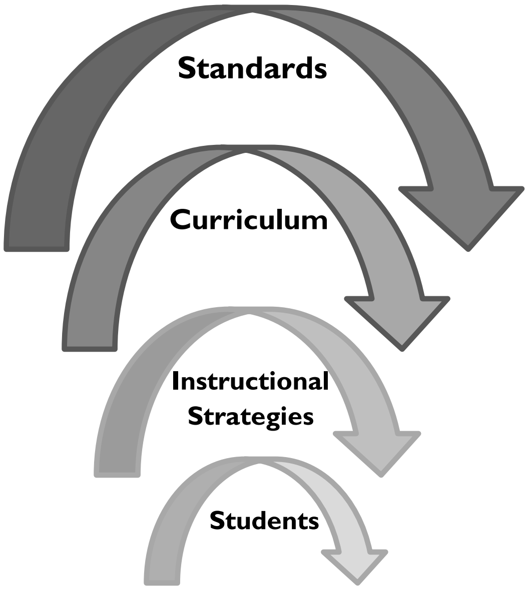
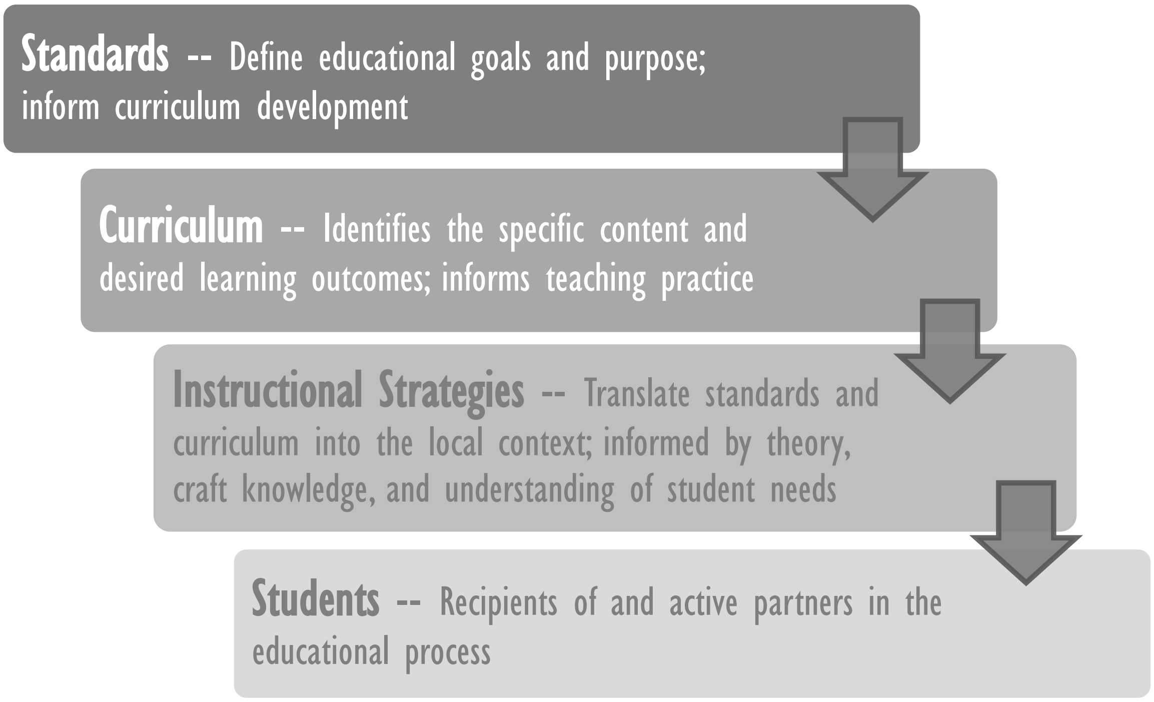


Figure 1. A graphical model of the standards-based education process.



Standards -- Define educational goals and purpose; inform curriculum development

Curriculum -- Identifies the specific content and desired learning outcomes; informs teaching practice

Instructional Strategies -- Translate standards and curriculum into the local context; informed by theory, craft knowledge, and understanding of student needs

Students -- Recipients of and active partners in the educational process

Figure 2. The function of each level within the standards-based education process.

Bybee (2000), contrasting his thinking about implementing standards-based curriculum before and after the release of national standards for science, noted with respect to the *Standards for Technological Literacy* that "although delivering a standards-based curriculum may adhere to educational theory, reform of the technology curriculum will not be [as] simple" (p. 27) as describing the characteristics of curriculum materials and instructional approaches and providing professional development experiences based on those, "because ultimately teachers have the responsibility for establishing and developing the connections between the content of the curriculum and the students' technological understanding and abilities" (p. 26). This touches on the critical role played by the students in this whole enterprise: without their willing participation in the enacted curriculum, the goals of the specified curriculum will not meet their mark; and the curriculum students actually *experience* is dependent on the skills of the teacher, the students' emotional and academic disposition toward the content, and their ability to understand the curriculum and what is expected of them, among other factors.

Viewing Effective Teaching through the STEM Lens

It is difficult to overstate the degree to which the acronym STEM has become ubiquitous in the last decade. Unfortunately, many use the acronym in a very ill-informed way: "*STEM* has been used as a conglomerate term, not as an integrative expression…[and] neither a clear and definitive educational purpose nor implications for school programs' instructional practices have been systematically developed" around the term (Bybee, 2013, p. 2). Nevertheless, its broad adoption in the educational lexicon serves to indicate the degree to which it has taken root (irrespective of individuals' rationales for championing STEM education). As such, it is an approach that cannot be ignored, and is instead a force that may be exploited to achieve disciplinary goals within each of the subjects represented.

As noted by Honey, Pearson, and Schweingruber (2014), the most recent standards in mathematics (*Common Core State Standards for Mathematics* [*CCSSM*]) and science (*Next Generation Science Standards* [*NGSS*]) both call for integration strategies that span the STEM fields of study and, in the case of the *NGSS*, they explicitly address technology and engineering. However, echoing the concerns of other proponents (and opponents) of integration, these authors wrote: "One challenge of implementing both the CCSSM and NGSS is to ensure the development of discipline-specific knowledge while also supporting connections across STEM" (p. 110). They further acknowledged that in the process of integration some subjects fare better than others in terms of student acquisition of desired learning outcomes.

T&E in the STEM Era

With respect to integration, Bybee (2013) provided one of the best explorations I have seen of the various perspectives that STEM integration can take in a chapter titled "What is Your Perspective of STEM Education?" Calls for incorporating T&E into science education date back to at least 1989 with the *Science for All Americans* document, but Bybee has been involved with technology education long enough to recognize more than others in the field of science the challenges T&E faces in this relationship, and "actively including technology and engineering in school programs" is the first and most significant challenge (Bybee, 2013, p. 3). Echoing this concern, Banks and Barlex (2014) wrote: "It is essential that the integrity of design & technology be maintained. It is all too easy for the learning intentions to become subverted so that the learning of mathematics or science dominates the proceedings. The simplistic and erroneous definition of technology as 'applied science' can easily lead to situations in which the application of science overrides all other considerations to the detraction of learning in design & technology" (p. 81). However, in their book Banks and Barlex do give a number of good, detailed examples of STEM integration.

Barak (2013) suggested that to overcome the difficulties inherent in adopting a STEM orientation, and in light of the recent efforts to replace technology education with technology and engineering education, T&E content, instructional strategies, and assessment tools should be designed "more carefully than in the past, taking into account the cognitive aspects of learning, the types of knowledge we want to teach the students, and how to develop gradually learners' aptitudes to tackle sophisticated scientific-technological problems" (p. 328). Yet, as Rose et al. (2015) noted, "the dynamic nature of the TE content domain makes it difficult to assume where the acceptable range of content competence might lie for a TE teacher striving for excellence" (p. 4). Barak recommended creation of an educational taxonomy for T&E that identifies the type and amount of "factual, procedural and conceptual knowledge" that should be included in the T&E curriculum (p. 325).

Both technology and engineering share the burden of being the sometimes misunderstood elements in the middle of the STEM acronym:

> In contrast to science, mathematics, and even technology education, all of which have established learning standards and a long history in the K–12 curriculum, the teaching of engineering in elementary and secondary schools is still very much a work in progress, and a number of basic questions remain unanswered. How should engineering be taught in grades K–12? What types of instructional materials and curricula are being used? How does engineering education "interact" with other STEM subjects? In particular, how does K–12 engineering instruction incorporate science, technology, and mathematics concepts, and how are these subjects used to provide a context for exploring engineering concepts? (Katehi, Pearson, & Feder, 2009, p. 6)

It would be shortsighted to assume that the alliance between technology and engineering is anything but uneasy or, at the very least, ill-defined. As the tone of some passages within the NAE book illustrates, the engineering community is not ready to declare technology and engineering to be two sides of the same coin (nor, it must be said, are all technology educators ready to do so):

> The review of curricula revealed that technology in K–12 engineering education has primarily been used to illustrate the products of engineering and to provide a context for thinking about engineering design. In only a few cases were examples of engineering used to elucidate ideas related to other aspects of technological literacy, such as the nature and history of technology or the

> cultural, social, economic, and political dimensions of technology development. (Katehi,Pearson, & Feder, 2009, p. 8)

Nevertheless, as will be proposed in a later section of this paper, compelling arguments can be made for identifying and exploring the commonalities between these two fields, and for entering into a more equal partnership with our comrades in the middle of STEM.

Good Teaching in Any Context

As mentioned earlier, many of the studies of effective teaching include reference to the affective attributes and tendencies of good teachers. In addition, there are some overarching teaching practices that can be fruitfully employed in many K-12 classrooms, regardless of the subject being taught. It is therefore important to provide an overview of these practices and characteristics before diving more specifically into the instructional strategies featured prominently in STEM classrooms.

In their examination of 20 exemplary science teachers in Western Australia, Tobin and Fraser (1987) wrote at length about one specific characteristic of these classrooms, in contrast to the comparison classrooms:

> The exemplary teachers had well-managed classes and were able to concentrate on establishing a productive learning environment. Each exemplary teacher viewed teaching in terms of facilitating student learning. …The striking similarity was in the manner in which the teachers interacted with students. Interactions were not strained, but were friendly, relaxed, private and respectful. Humour [*sic*] was used in a subtle and low key manner….The important similarity in the approach to teaching was that teachers created situations where students could identify and act on the instructional cues that were necessary for appropriate engagement (p. 25).

Alsop (2005) commented on the importance of teachers' subject confidence in effective science teaching and in making science something that students care about and want to engage in. Task engagement on the part of students is shaped in large part on student interest in the learning activities and how useful students perceive the learning tasks to be. Teachers must also identify prerequisite understandings needed to connect ideas within a lesson, and provide "timely scaffolds or frameworks" to facilitate those connections. "Even when students have the necessary background knowledge, this does not ensure that they recognize its relevance" (Taber, 2005, p. 130). Good teachers will also employ a variety of techniques to engage students actively on multiple levels; Przywolnik (2005) described using role-playing and using students as "props" in demonstrating scientific concepts in astronomy, for example. Summarizing a range of other techniques, Wilson and Mant (2011) stated:

> Strategies that actively engage pupils in their learning (for example, discussion, problem solving and practical work) are recognised [*sic*] by pupils as part of an exemplary teacher's repertoire. There is also resonance with the findings of Mant, Wilson and Coates (2007) that giving space for discussion of ideas in science increases engagement and achievement and that pupils appreciate the challenge of more thinking for themselves within science lessons. (p. 124)

Hassard (2005) reported on a meta-analysis of studies that linked STEM instructional methods with increased learning outcomes and the "clustering of broad patterns of behaviors" (p. 29) or "interactive teaching strategies" that effective teachers use:

- Clarity – provides clear and understandable explanations.
- Variety – uses a variety of strategies to reinforce learning, a diversity of questions, and hands-on materials.
- Task orientation – spends more time on content than on classroom procedures.
- On-task behaviors – maximizes the amount of time students spend engaged with materials and activities.
- Success rates – designs learning tasks that lead to high success rates but that are seen as meaningful by students.
- Using student ideas – acknowledges, summarizes, and applies student comments to instruction, which can lead to increased self-esteem in students.
- Instructional set – helps students to conceptually organize the lesson and its content both before and after the fact.
- Questioning – asks a variety of questions and incorporates sufficient wait time.
- Enthusiasm – shows involvement, excitement, and demonstrated interest in the topic.

From the students' perspective, Wilson and Mant (2011) reported on their findings from a survey of over 5000 12-year old students to gauge their perceptions about science teachers. Among those teachers considered exemplary based on the survey methods used, the following characteristics emerged: Good teachers were said to be "clear explainers," to engage students in discussion and problem solving activities, to incorporate less teacher lecture and demonstration and more work by the students on their own, and to contextualize the science content (p. 124).

Trends and Innovations in STEM Education

Many modern accounts of teaching practice within STEM education include the words "problem-based learning," "inquiry," "problem solving," or "design." These types of approaches are believed to involve students in learning that allows them to think critically, to become more actively engaged, and to construct more enduring understanding of the topics. These approaches are also seen as being inherently interdisciplinary, a key element of good STEM educational experiences (Asghar, Ellington, Rice, Johnson, & Prime, 2012).

Asghar et al. (2012) wrote about a state-funded professional development project in Maryland whose goal was to help teachers and school administrators design and implement STEM academies within their districts. The model they used was problem-based learning (PBL) and the focus of their research was on "teachers' experiences of professional development for interdisciplinary teaching in STEM" (p. 87). In particular, they assumed that math and science teachers, whose preparation is so discipline-specific, "would need focused professional development to equip them to transcend those disciplinary boundaries in order to teach interdisciplinary subject matter" (p. 87). These researchers acknowledged that math and science teachers often lack experience in technology and engineering skills, may have limited experience with PBL, and may face difficulties in managing collaborative PBL and assessment. Affirming the focus on PBL and STEM integration, Honey, Pearson, and Schweingruber (2014) wrote that "engineering design, like problem-based learning (PBL), is associated with a large number of efforts to teach the STEM subjects in an integrated fashion. Science inquiry, engineering design, and PBL share features that can provide students with opportunities to apply STEM concepts and engage in STEM practices in interesting and relevant contexts" (p. 43).

Based on their survey of 49 National Science Foundation Advanced Technological Education (ATE) program awardees whose projects focused on some aspect of K-12 education, Strobel and Mendoza Diaz (2012) characterized the elements of these projects. The primary audiences for the projects represented were students (33%) or teachers (33%), and among the dominant pedagogical models used within these projects "hands-on" learning ranked the highest, at 32%, followed by "project based learning" (30%) and "laboratory practice" (22%). "Guided inquiry" was identified by 18% (p. 13). In their discussion, Strobel and Mendoza Diaz stated: "Pertaining to the issue of pedagogical considerations, it was notable that most ATE project representatives have interest and knowledge in new approaches to technology and engineering education, namely, "hands-on" activities, project based learning, or even guided inquiry (p. 18).

Through his examination of the STEM literature, Anderson (2010) identified the following characteristics of high quality STEM programs:

1. Programs should broadly address student learning, including core content knowledge and critical thinking skills as defined by the relevant standards from professional organizations such as the International Technology and Engineering Educators Association (ITEA), the International Society for Technology in Education (ISTE), the National Research Council (NRC), the National Council for Teachers of Mathematics (NCTM), and the National Science Teachers Association (NSTA);
2. Programs should address student engagement (by illustrating the value of STEM in students' lives, as well as building interest in STEM fields and encouraging students to pursue STEM-related careers);
3. Programs should have an over-arching STEM "framework" which clearly maps standards for knowledge, skills, and dispositions to curricular activities;
4. Programs should integrate the teaching of all four STEM areas into a "meta-discipline";
5. Programs should ensure that all students have an opportunity to learn the "design" process (a core part of engineering), including "Global Engineering" (a system design process for a geographically distributed environment).
6. Programs should provide opportunities for open-ended "research-based" activities supported by cutting-edge technology.
7. Programs should provide activities that are hands-on, technology-based, applied, holistic, real world, integrative, collaborative, and personalized.
8. Programs should have a strong evaluative component that allows both formative and summative evaluation.

9. Programs should have a strong professional development component for teachers and administrators;
10. Programs should develop partnerships among a broad range of education stakeholders, including schools, businesses, higher education, government, and community, in order to provide authentic mentoring relationships and internships for students. (pp. 2-3)

Not all of these elements relate specifically to the teacher, but this list does serve to highlight and summarize the attributes associated with good STEM education, some of which will be examined more fully in the remainder of this paper.

The Role of the Teacher as Facilitator

A great number of articles describing effective teaching in technology and other STEM subjects refer to the teacher as a "facilitator." It is helpful to elaborate on what we mean by this term, and Hassard (2005) provides a list of characteristics of the "facilitative science teacher" (p. 372). These teachers have effective classroom management behaviors, including awareness of what is happening in the classroom, ability to effectively handle multiple classroom activities at the same time, ability to make smooth transitions between activities, and ability to maintain momentum within a lesson. They are capable of enabling laboratory and small-group work, including providing for individual accountability, positive interdependence, and development of interpersonal skills among students. Such teachers can also encourage higher-level thinking skills by allowing students to help each other, giving students opportunities to revise their work, providing models of successful work, and implementing review and feedback sessions.

As facilitator, the teacher must provide for meaningful and effective learning situations, but will take more of a side or what some term a consulting role. Knowing when to step in to help students is a skill that can be developed with experience. "The amount and extent of intervention necessary is not easy to judge. Too early and too directive an intervention and students will, thereafter, wait for teachers to tell them how to do it. Too late and too vague an intervention and students are likely to give up in exasperation" (Hodson, 2005, p. 102).

Inquiry Learning

Inquiry-based instruction is considered an important teaching strategy in science because it involves students in investigating questions and using data to answer those questions. According to Capps and Crawford (2013), reviews of the literature on science learning "indicated a clear positive trend between inquiry-based instruction and conceptual understanding for students" (p. 498). Yager (2009) emphasized that inquiry is "central" to how practice in science is defined (p. x), and by engaging in inquiry learning students can gain insights into the nature of science, which is seen as an essential part of understanding in science. "For example, students should understand that scientists ask questions, perform different types of investigations, and produce explanations based on their observations…. These understandings about inquiry reflect the philosophical and socio-historical natures of scientific inquiry and [the nature of science]…. Abilities to do inquiry include asking and identifying questions, planning and designing experiments, collecting data using data, and connecting data as evidence with explanations" (Capps & Crawford, 2013, p. 499).

Project-Based Learning

Project-based learning has been a hallmark of instruction within technology education classrooms, both historically and currently. Nevertheless, it is also considered a feature of modern STEM classrooms because it emphasizes activities that are interdisciplinary and student-centered. The same can be said about problem-based learning (PBL), but Banks and Barlex distinguished between the two:

> The difference between project-based learning and problem-based learning is essentially one of *ownership* of the learning activities. PBL has tended to be a way of configuring the curriculum and relating what students know to actual, real-world problems.… Project-based learning has been more about a pupil choosing an extended activity that [he or she] is interested in and using it as a vehicle for demonstrating current capabilities…. the degree of latitude actually allowed to the pupils to follow their own interests in project-based learning has to be tempered by restraints of available resources and time, classroom management issues…and the ever-pressing need to "cover the syllabus. (Banks & Barlex, 2014, p. 141).

In light of the concerns about resources, Banks and Barlex suggested that project-based approaches must be balanced with other types of instructional strategies such as demonstrations, discussions, and shorter-duration activities. They described, for example, "design-and-make" activities chosen by the teacher to specifically address some aspect of the curriculum and through which students' skills and knowledge base can be progressively built up (p. 143).

Problem-Based Learning

A key characteristic of PBL is that learning is more open-ended, initiated by presenting students with a "problematic situation," followed by activity that is more student-directed, and focused on problem solutions or end products that are not specified by the teacher (Asghar et al., 2012). "Hence, in PBL the learners are charged with both defining the problem, developing the solution and identifying the resources to refine their solutions, and the tutor serves as one possible resource to achieve their goals" (p. 95). PBL is considered to be a form of problem-solving, and is "grounded in constructivist pedagogy" (Hill & Smith, 2005, p. 136). Hill and Smith go on to identify some recurrent characteristics of PBL: It makes use of "real-life problems" and engages students in "authentic activities" that are interdisciplinary in nature; students work in groups; "learners are encouraged to think critically, creatively and reflectively"; and the faculty who facilitate these learning experiences "guide, probe and support group and individual learning" (Hill & Smith, 2005, p. 137). According to Hill and Smith, PBL "continues to define technology and technology education today and is also proving relevant to science education" (p. 136).

Another typical feature of PBL is that assessment is integrated into the lessons, during which students evaluate their work on an ongoing basis and teachers provide formative feedback (Banks & Barlex, 2014).

Using slightly different language, Hawkins (2014) described "challenge-based learning" (p. 83) activities that she has used with her middle school students in Tennessee. These activities were drawn from a set of "Legacy Cycle" lessons where challenges served as "anchors for learning." In one example, The "TN River Crisis Challenge" (p. 84), her students acted as an emergency response team monitoring and finding solutions for a scenario in which an earthquake threatened dams along the Tennessee River. Hawkins noted that her "struggling" learners showed the best gains through this kind of scenario-based learning" (p. 86).

Alsop (2005) commented that tasks which incorporate student choice are more relevant in terms of adoption of mastery goals for students. He noted, however, "a delicate balance [must be] struck between self-direction and teacher mentoring" (p. 152). Alsop also acknowledged that what makes something relevant to students differs depending on the learner, but suggested that "situating school science activities within the context of…socio-scientific issues (concerning health and the environment) can serve to increase relevance" to students (p.155).

Other STEM Strategies

Based on these short descriptions of prominent approaches to STEM teaching and learning it should be clear that they are not the only recommended instructional strategies, and how and where they are employed depends on the setting, the learners, and the goals of particular curricular units. This section includes discussion of other recommended strategies for teaching in STEM.

In describing how teachers can "establish a culture of learning" consistent with the theories of Vygotsky, Hassard (2005) identifies "talking science, reading science, [and] writing science" (p. 341) as critical. All of these can be considered means to engage students in active learning, and align with the engineering habits of mind described by Katehi, Pearson, and Feder (2009), as well as with the emphasis on understanding the nature of science described by Alsop et al. (2005). In a related vein, various methods can be used for supporting "argumentation" that leads to an understanding of different positions in science. These include role playing, group discussion, and use of writing where students are asked to highlight the pros and cons of issues. All of these can "enable the structuring of knowledge and understanding" (Alsop et al., 2005, p. 112).

Pedretti (2005) wrote about strategies used to teach science from a Science, Technology, Society (STS) approach. These include using historical perspectives to "give science a human face;" (p. 118); using real-life "issues" as the basis for learning experiences or as curriculum organizers; use of role-play, as above, to allow students to understand the positions of various stakeholders; bringing in outside experts to provide information about the issue; and providing scaffolding for the information gathering, analysis, discussion, and organization of observations and arguments leading to decision making about the issue at hand.

Within the field of technology education, Herschbach (2009) noted that there has been an important shift toward emphasizing both the technical *and* the intellectual processes "associated with technological activity" (p. 320). "The crucial nexus is between the process functions (both domain and non-domain-specific) and the activity. It is through activity that meaning is achieved" (p. 321). These will be examined in more detail in the final section of this paper.

Hodson (2005) noted that there is no "simple algorithm" for conducting scientific inquiry, the conduct of which can be "complex, messy, fluid and uncertain." Moreover, the outcomes of work in science (as well as in T&E, it could readily be argued) are dependent on the question under investigation, the context, the level of understanding of the learner, the facilities available in which to do the work, and more. He therefore suggested a type of "apprenticeship" in which students do science "alongside a skilled and experienced practitioner who can provide on-the-job support, criticism and advice" (Hodson, 2005, p. 101). Hodson also noted that in understanding the nature of science it's important that students understand science can be biased and culturally influenced; in other words, that scientists are just people, too.

Retrospect and Prospect

Everything Old is New Again

Kelley (2012) provided an excellent essay titled "Voices from the Past: Messages for a STEM Future," in which he examined the historical influences in technology education: "Technology education's longstanding history in problem- and project-based learning, design- and engineering-related pedagogical approach is over a century old and grounded in theories of Comenius, Rousseau, Pestalozzi, Froebel, Herbart, Sheldon, and Dewey" (Kelley, 2012, p. 34). He also detailed our rich history with the use of curriculum integration and the project method—the same types of "innovations" being touted today within STEM education:

> These are several of examples of the history of technology education and engineering that illustrate that both fields are returning to their pedagogical roots by providing practical applications of design and engineering instruction. Although both fields often promote these methods as new innovations, the reality is that these approaches to education are well over a century old. (p. 37)

Kelley noted that "the early roots of technology education are closely intertwined with the development of the American engineering schools" (p. 35), a shared lineage that needs to be reignited today.

One can look to the not-as-distant past to find other examples of the kinds of "contemporary" approaches associated with STEM education today. For example, in *Innovative Programs in Industrial Education* (1970), Cochran described several approaches to teaching industrial arts, among them "The Richmond Plan" (p. 34). Developed and implemented in Richmond, California, The Richmond Plan was a "two-year preengineering [*sic*] technology sequence of four integrated and correlated courses beginning in the eleventh grade" (p. 35). Collectively, these courses provided experiences in English, science (physics and chemistry), math, and "technical laboratories" (p. 35). However, in spite of the commitment to identifying the "natural relationships between the subjects" (p. 35) and clear attempts for collaboration among the teachers involved, Cochran noted "the technical area [was] used primarily for reinforcing [other academic] content and [for] motivating the student" (p. 36).

Donald Maley, in his influential *Maryland Plan,* emphasized that "industrial arts can provide meaningful educational experiences for the integration of subject matter" by adding "reality, concreteness, and relevancy" to the students' work in other classes (p. 6). The detailed map of a Grades 7 through 9 curriculum plan included elements that align with the project-based and problem-based approaches considered innovative by STEM educators today. For example, in Grade 9 the plan called for approaches ranging from "contemporary units" and "research and experimentation" to "technical development" projects (p. 124). Highlights of the latter included student selection of the focus of their "problem-project"and in-depth study of the selected topic. In Maley's estimation, such a project would facilitate student engagement and development of independent learning skills, and would "invariably" involve using an interdisciplinary approach to the problem-project (p. 124).

The Need to Strengthen Alliances

After engaging in the review of literature needed to complete this paper, an important conclusion I reached personally was of the need for technology education and engineering to work collaboratively to establish a larger T&E presence in the K-12 arena. I was therefore delighted to read the following statement from Kelley (2012);

> The author of this article would like to suggest that T and the E should work harder to provide support for one another. Of all the STEM stakeholders who sit at the "STEM table," members of the technology and engineering fields are best positioned to sit the closest; as a result their contribution to K-12 STEM education will be strengthened. (p. 39).

What follow are some further supports for this argument, and some suggestions for how deeper collaboration might be structured.

The National Academy of Engineering has perhaps done the most to move K-12 engineering into the limelight. The NAE Standards Committee, however, has recommended integrating engineering into existing standards rather than creating stand-alone engineering standards (Carr, Bennett, & Strobel, 2012). Nevertheless, a number of groups (including Carr et al.) have worked to identify the "big ideas" that characterize "doing engineering" (Table 1), and movement toward K-12 engineering content standards seems inevitable.

Interestingly, if one overlays lists like the one presented in Table 1 with similar lists of concepts and strategies associated with technology, considerable overlap is apparent. For example, in the list of "intellectual processes of technologists" compiled by Wicklein and

Rojewski (1999; see also Hill & Wicklein, 1999), there is overlap with virtually all of the "engineering ideas" identified by Carr et al.

These common elements show that technology and engineering would not be working at cross purposes to join forces to develop curriculum models, professional development models, and instructional approaches to enhance the overall STEM landscape. In so doing, we could build a broad community of practice that could lead to effective integrated STEM education (Honey, Pearson, & Schweingruber, 2014).

Table 1. *Results of a Cross-State Analysis of Engineering Ideas Being Taught in K-12 Education* (Carr, Bennett, & Strobel, 2012, p. 556)

- Identifying criteria, constraints, and problems
- Evaluating, redesigning and modifying products and models
- Evaluating effectiveness of solutions
- Devising a product or process to solve a problem
- Describing the reasoning of designs and solutions
- Making models, prototypes, and sketches
- Designing products and systems
- Selecting appropriate materials, best solutions, or effective approaches
- Explaining the solution and design factors
- Developing plans, layouts, designs, solutions, and processes
- Creating solutions, prototypes, and graphics
- Communicating the problem, design, or solution
- Proposing solutions and designs
- Defining problems
- Brainstorming solutions, designs, design questions, and plans
- Constructing designs, prototypes, and models
- Applying criteria, constraints, and mathematical models
- Improving solutions or models
- Producing flow charts, system plans, solution designs, blue prints, and production procedures

Implications for Technology and Engineering Teacher Education

The road toward deeper collaboration may not be easy, however. The nine views of STEM education presented by Bybee (2013) is unique in that as a scientist he has so clearly described the prevailing perspectives or approaches to STEM. For example, in their "Vision of Pre-college Engineering Education," Marshall and Berland (2012) presented a typical vision of K-12 engineering education that ignores technology and posits the role of engineering as *the* tool we use to provide contexts for learning math and science. In 2014, the NSTA published its book *Exemplary STEM Programs* (Yager & Brunkhorst), but technology shows up primarily in reference to instructional technologies used to teach science content.

In somewhat blunt fashion, Honey, Pearson, and Schweingruber (2014) provided a pragmatic observation of the limited role of technology in STEM: "Although they are in the majority by a wide margin, science and mathematics teachers are not the only teachers of K-12 STEM. Some 45 undergraduate programs in the United State prepare technology teachers" (p. 118). Our biggest challenge may indeed be having enough critical mass to even be present at the metaphorical table of STEM. Recent recruiting initiatives undertaken by the ITEEA as part of its strategic plan may help to address this problem.

Bybee (2013) talked about context-based STEM education as a challenge because it "emphasizes competency in addressing situations, problems, or issues, and not exclusively knowledge of concepts and processes within the respective STEM disciplines" (p. 3). In an effort to move STEM beyond being a mere "slogan" (p. 4) and into an approach with a clear educational purpose, Bybee recommended a focus on identifying and developing a broader STEM literacy that includes:

- knowledge, attitudes, and skills to identify questions and problems in life situations, explain the natural and designed world, and draw evidence-based conclusions about STEM-related issues;
- understanding of the characteristic features of STEM disciplines as forms of human knowledge, inquiry, and design;
- awareness of how STEM disciplines shape our material, intellectual, and cultural environments; and
- willingness to engage in STEM-related issues and with the ideas of science, technology, engineering, and mathematics as a constructive, concerned, and reflective citizen. (p. 5)

One of the tasks in achieving this type of STEM education will be to develop innovative models for curricula and teaching. A finding from the Rose et al. (2015) study was that "the traditional role of a TE teacher is narrowing to an implementer of curricula because competencies related to fulfilling roles of curricular developer, curriculum evaluator, and facility developer were not among those competencies judged to be critically important" (p. 18). It's possible that this signals the availability of established models like ITEEA's *Engineering by Design* curriculum or *Project Lead the Way*, but in any case the path is clear for introduction of new approaches to STEM teaching and learning.

Regarding teacher professional development, both pre-service and in-service, challenges abound for all disciplines within the STEM spectrum to provide the kinds of resources and supports that will lead to exemplary teaching practice. For example, in promoting inquiry learning, Yager asked: "Why do we leave our students with fewer questions after our instruction than before real science experiences begin? Why do we not care more about the fact that students are less curious after instruction than before and have more negative views of science, science careers, and science teachers?" (2009, p. xiv). Capps and Crawford (2013) lamented, "It was particularly troubling that many of the teachers in this study believed they were teaching science as inquiry even when they were not. This calls into question the impact of reform-based documents like the standards. If some of the best teachers we could recruit failed to demonstrate an understanding of inquiry-based instruction and did not teach science as inquiry, then who does?" (p. 523). In their extended involvement with helping Maryland school districts develop STEM education via problem-based learning, Asghar et al. (2012) found "Teachers exhibited resistance to the implementation of our model. Participants explicitly shared their apprehensions and concerns about using STEM approach in their instructional settings during workshop discussions, individual conversations, and focus group discussions" (p. 103).

One strand of future research in T&E teacher education should focus on doing the kinds of analysis of practice demonstrated by Capps and Crawford (2013). Their detailed observations of both teaching practice and of teachers' reflection on practice could provide necessary information for creation of effective professional development models for T&E teachers.

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