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This article identifies a number of issues associated with current STEM education reform efforts, especially with regard to efforts to integrate engineering education into the K-12 curriculum. Precollege engineering is especially problematic in STEM reform since there is no well-established tradition of engineering in the K-12 curriculum. This discussion aims at identifying some of the issues and problems that serve to impede implementation of engineering education in the K-12 environment. Historically, engineering education has been the purview of higher education, and the epistemology of engineering education has not evolved to specifically inform the exigencies of K-12 education.

There also are little in the way of cohesive standards that establish appropriate precollege engineering knowledge and skills and provide a framework for shared understandings, cooperative partnerships across institutional boundaries, curricular development and implementation, and teacher preparation and professional development. The lack of standards and an epistemic foundation and tradition in K-12 engineering results in significant gaps in experience and knowledge to inform implementation, which is proceeding in schools despite these glaring obstacles, driven by legislative mandate, STEM funding initiatives, workforce demand, and other compelling forces. The lack of systemic infrastructure and support mechanisms for preengineering (such as are found in the sciences, mathematics, and other academic disciplines already participating in K-12 education) have resulted in a situation in which there is no clear, generally agreed upon standards and definition of a body of engineering knowledge, skills, and activities that constitute appropriate curricular content for teaching and learning in K-12 education.

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Problems Associated with a Lack of Cohesive Policy in K-12 Pre-college Engineering

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Abstract

This article identifies a number of issues associated with current STEM education reform efforts, especially with regard to efforts to integrate engineering education into the K-12 curriculum. Precollege engineering is especially problematic in STEM reform since there is no well-established tradition of engineering in the K-12 curriculum. This discussion aims at identifying some of the issues and problems that serve to impede implementation of engineering education in the K-12 environment. Historically, engineering education has been the purview of higher education, and the epistemology of engineering education has not evolved to specifically inform the exigencies of K-12 education. There also is little in the way of cohesive standards that establish appropriate precollege engineering knowledge and skills and to provide a framework for shared understandings, cooperative partnerships across institutional boundaries, curricular development and implementation, and teacher preparation and professional development. The lack of standards and an epistemic foundation and tradition in K-12 engineering results in significant gaps in experience and knowledge to inform implementation, which is proceeding in schools despite these glaring obstacles—driven by legislative mandate, STEM funding initiatives, workforce demand, and other compelling forces. The lack of systemic infrastructure and support mechanisms for preengineering—such as are found in the sciences, mathematics, and other academic disciplines already participating in K-12 education—have resulted in a situation in which there is no clear, generally agreed upon standards and definition of a body of engineering knowledge, skills, and activities that constitute appropriate curricular content for teaching and learning in K-12 education.

Key Words: STEM reform, precollege engineering, National Academy of Engineering, precollege engineering curriculum.

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Overview

In the decade since release of the Glenn Commission report, *Before It's Too Late: A Report to the Nation* (2000), we have seen a remarkable proliferation of STEM education reform initiatives at the national, state, and local levels. Alarmed by declining student performance in mathematics and science, coupled with a continuing trend of decreasing enrollments and poor retention in STEM degree programs—the nonpartisan Glenn committee voiced grave concern about whether our educational system could produce the diverse scientific and technical workforce necessary for the United States to remain competitive in a global economy that is increasingly driven by technologic development and innovation. Recognizing that competitiveness also requires a citizenry capable of mastering the scientific and technical concepts and skills to function in work and home environments requiring ever-increasing technological sophistication, the Commission also advocated teaching STEM subjects as interrelated concepts and skills to more closely reflect how they are applied in the workplace.

The Glenn report and more recent studies by the National Academies (2007, 2009) indicate wide consensus that better preparation of K-12 teachers and a more rigorous K-12 curriculum are necessary to improve student performance in STEM subjects at college and career levels. The Glenn Commission also recognized that raising the pay and professional status of teachers will be necessary to attract and retain high quality teachers capable of affecting the changes in STEM education that the committee advocated.

Precollege engineering is especially problematic in STEM education reform since there is no well-established tradition of engineering in the K-12 curriculum or as part of teacher preparation and certification processes. The result—most K-12 teachers and administrators are typically ill prepared to adequately advise students about engineering careers, much less introduce engineering knowledge and skills into the classroom. While there is a growing appreciation that engineering may be a positive vehicle to motivate K-12 student study of other STEM subjects (AeA, 2005; NAE, 2009; NSB, 2007), some emerging research indicates that there are circumstances in which this position may not be entirely valid (Tran & Nathan, 2010). However, significant gaps in experience with engineering in the K-12 setting make these kinds of discussions difficult at best.

Establishing the Estacado Precollege Engineering Academy

The release of the Glenn Commission report also coincided with the pilot year of the Estacado High School Precollege Engineering Academy that we helped establish in partnership between Lubbock ISD and the Texas Tech University (TTU) Center for Engineering Outreach. Estacado High School has an overwhelming majority population of low-income African-American and Hispanic students. Historically, the percentage of Estacado High School graduates pursuing postsecondary education perennially has earned it an Underperforming High School classification in Texas. The Precollege Engineering Academy is still in operation, and we are extremely proud that more than 80 percent of its students go to college upon graduation. However, the Academy curriculum is very different today than we originally conceived it. For that matter, the TTU Center for Engineering Outreach has also changed significantly. We are now the Texas Tech University T-STEM Center, a component of the Texas High School Project—a statewide STEM initiative that comprises 7 T-STEM Centers and 52 STEM Academies, as well as early-college high schools and other innovative education programs.

Some of the changes we have experienced are a result of STEM education reform initiatives, some result from legislative and regulatory agency mandate, but all of our current activities are tempered by experience that we have gained along the way—especially with regard to working in an environment with very different institutional objectives and political constraints than are found in higher education. For example, 10 years ago there was little substantive preengineering curriculum available, and the courses in the state inventory with *engineering* in their title were perhaps best characterized as holdovers from a time when Career and Technology Education (CTE) was called Industrial Arts.

Initially, our main strategy to engage students in learning engineering concepts and skills was to shoehorn engineering design projects or other engineering-related content into existing science courses and to sponsor afterschool programs, competitions, and similar learning enrichment experiences. Later we were able to apply for innovative course status for engineering courses that we developed with teachers and administrators at Estacado, when this status was allowed under the Career and Technology Education section of the Texas Essential Knowledge and Skills (TEKS) course standards. Innovative courses are no longer an option in Texas,

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but there are now standards for several courses with significant engineering content, and the Texas Board of Education recently approved TEKS standards for a new capstone engineering course: Engineering Design and Problem Solving.

The Topography of STEM Education Reform

While STEM education reform efforts have proliferated and gained traction, resulting in some of the changes that we have observed in the topography of K-12 education over the past decade, many problems and issues that hampered STEM implementation ten years ago continue to serve as barriers to an integrated STEM curriculum—especially to the integration of engineering content. However, driven by legislative mandate, STEM funding initiatives, workforce demand, and other compelling forces—implementation of precollege engineering and other STEM programs is proceeding in schools despite some glaring concerns and gaps in experience with K-12 engineering.

The following discussion identifies some issues that the authors believe are significant obstacles that continue to hamper implementation of engineering in K-12 education. We expect that our experience and frequent frustration with these issues are not unique and recognize that some may perceive and experience them very differently from us. Our depiction of the educational landscape is often painted with very broad strokes, because many of the underlying practical issues to STEM integration in the K-12 classroom are much larger, albeit sometimes deceptively subtle barriers to all human enterprise—epistemic differences, cultural proclivities, and territorialism, to name a few. One does not have to look closely at any university campus to conclude that momentum in the construction of knowledge has been toward splintering the scope of larger academic disciplines into smaller fields of specialization. We are not questioning the value or the reasons for this topography. We make this observation in recognition that STEM reform requires a paradigm shift toward integration of disciplinary knowledge and skills against inertia and cultural boundaries existent in our educational system.

In the following section we will discuss issues stemming from different epistemic traditions involved in STEM reform, a lack of cohesive standards for preengineering knowledge and skills, and issues related to curriculum resources available to schools that prompted us to develop our FRAME engineering design model, which we will discuss in the last section. We do not claim to have solutions for many of the practical questions or problems of integrating engineering into the K-12 STEM curriculum. We simply offer this discussion through the lens of our experience working to implement precollege engineering education in Texas with the hope that it may inform the efforts of others in the field.

Barriers to Implementing K-12 Engineering

Engineering in K-12 Education, a report released last year by the National Academy of Engineering (NAE, 2009) and the National Research Council (NRC) makes a number of convincing arguments for engineering as "a catalyst for a more interconnected and effective K-12 STEM education system" (p. 1). And in the spirit of true reform, the NAE recognizes that this outcome "will require significant rethinking of what STEM education can and should be" (p. 1).

In their review of the NAE report, Rogers, Wendell, and Foster (2010) point out that the committee's discussion of the potential for precollege engineering education substantially references engineering education research, but that some of the practical issues regarding implementation of precollege engineering education do not receive as much attention in the report. For example, the NAE recognizes that there is often a conceptual disconnect between how engineering is perceived and taught in the K-12 classroom and the generally accepted disciplinary perspectives and practices within the epistemic traditions of engineering education.

The report also recognizes that this fundamental problem is compounded by a lack of standards for knowledge and skills appropriate to preengineering education, as well as the lack of comprehensive, standards-driven teacher preparation mechanisms and curriculum standards. Rogers et al. rightfully argue that summaries and analyses of various curricular resources and reviews of engineering research that examine the impact of engineering curricula on students' mathematics and science achievement that are undertaken in the report leave many practical questions unanswered.

Issues Related to Epistemology

We should probably question, or at least put into perspective, the value of purely quantitative examinations in an environment that is poorly defined and understood, and carefully consider what these methods actually tell us about how individual classroom implementations impact the effectiveness of these curricula. We agree with the reviewers that qualitative studies are also needed to capture richer descriptions and experiential narratives to depict more fully and to help understand exigencies of K-12 engineering education as experienced in practice. And there are obvious merits to bringing a wider range of disciplinary knowledge and skills into producing theoretical and practical models, which could better inform implementation efforts, as the reviewers suggest. The engineering education literature overwhelmingly draws upon the experience of university engineering colleges, so attempts to apply lessons from the literature to K-12 engineering education leave substantial room for skepticism about their power to account for fundamentally different mandates, institutional perspectives, and functional environments, which separate institutions of higher education and K-12 education.

We use the term "epistemology" in the original Aristotelian sense, as a way of reasoning and understanding the things we encounter in the world. Certainly we all bring all of our experience to the table all of the time, but Aristotle makes the distinction that training and practice are the means by which intellect is shaped and developed (Aristotle, trans 1998[1925]). The trend toward more specialized fields of study and practice has resulted in narrowing disciplinary understandings of theory and practice with perspectives that privilege theoretical stances, methods, research results, publications, and other ways of knowing that have emerged from their own specialized traditions and academic pursuits. And while we recognize and concede that there is significant overlap in the topics, literature, and other interests among various disciplinary areas—as well as individual experience, cultural proclivities, institutional structure, shared practice, and a host of other factors, which obscure and blur the boundaries that we are attempting to describe—the Aristotelian distinction that training and practice shape understanding serves our purpose here to account for many of the problems we have experienced in working toward implementing engineering into the K-12 setting.

The NAE report and others (Busch-Vishniac & Jarosz, 2004) express concern that the profession of engineering is still poorly understood by the public and that misconceptions about what engineers do in practice may actually serve to discourage women and ethnic minority populations from pursuing engineering careers. Prior to STEM reform efforts, there was little incentive for engineering colleges to engage in K-12 education, and the tendency was to turn inward toward research and teaching the engineering sciences. Engineering colleges have historically afforded limited opportunities to develop personal or professional relationships or first-hand experience dealing with very different political constraints and other realities of the K-12 environment—particularly in comparison with the various academic units at universities involved in teacher preparation, which develop strong connections to K-12 education through the student population they serve and in their teaching and research missions.

Funding trends and increased awareness of STEM reform are having the desired effect of substantially increasing participation by engineering educators, practitioners, and professional organizations in efforts toward STEM integration. When we began to develop the Estacado Precollege Engineering Academy, not only was the lack of understanding about the study and practice of engineering a source of frustration in our efforts, but also our lack of understanding of the structure, practice, and other constraints of K-12 education proved an equally significant barrier to developing the program. For example, the sequence of course work in mathematics, physics, and the sciences proved an insurmountable barrier to approximating a typical university model for engineering education of first requiring a foundation in these subjects and then teaching students applications for this content knowledge in the engineering sciences.

It is clear that there is a significant learning curve that will have to take place with what can be accomplished and what constitutes appropriate engineering knowledge and skills within the exigencies of the K-12 environment. However, it seems reasonable to assume that through developing content standards, programs for certification of precollege engineering teachers, and other mechanisms that will be required to integrate engineering knowledge and skills into K-12 STEM curriculum, the process will eventually provide a framework for creating authentic connections between K-12 education, engineering education, and other academic disciplines involved in curricular development and teacher preparation.

Our experience has been that the current literature and traditions in engineering education provide little in the way of a valid epistemic foundation for precollege engineering. Additionally, as STEM reform has gained momentum and opened doors for engineering educator and practitioner involvement in K-12 education, discourse is emerging that considers vertical alignment between prevailing higher education models for engineering education and K-12 engineering, which has potential to significantly improve recruitment and retention in engineering degree programs.

Issues Engendered by a Lack of Standards for Precollege Engineering

We commend the NAE committee for undertaking the task of sifting through and summarizing many of the resources, activities, and perspectives that have emerged from an area that has experienced explosive growth in both participation and program development over the past decade. The range of educational resources and activities that claim engineering content or engineering-based learning experiences in both formal and informal educational settings can make it difficult at times to see the forest for the trees.

In summarizing and evaluating a large number of these resources and programs, it can be tempting to draw conclusions that Rogers et al. (2010) describe as painting "a picture of a K-12 education space already populated with the raw ingredients for both innovative instruction and novel research" (p. 179). In the end, however, we have to agree with the reviewers' conclusion that effective implementation in the K-12 curriculum requires a systemic, well-defined framework for precollege engineering, which we have expanded upon to include specialized programs to educate and certify teachers of preengineering; policy support that includes education standards and evaluation criteria, shared theoretical and practical models; a robust body of research and literature; and other mechanisms, such as professional organizations to establish professional identity, represent specialized interests and needs, and encourage participation and ownership by all the stakeholders in precollege engineering.

We would not necessarily argue against the value of efforts to catalogue and evaluate the precollege engineering resources that are increasingly available to schools. However, without benefit of codified standards and policies for the educational infrastructure and support mechanisms, in K-12 engineering education-assessment rubrics and metrics will remain as protean and lacking congruent foundation

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as the content, programs, and other resources they aim to evaluate. Although schools are increasingly introducing engineering as part of the learning experiences they offer students, the process of choosing curricular components and professional development for their teachers is significantly undermined by the current state of affairs in which precollege engineering is too often whatever the person that writes the book or curriculum, develops the website, or provides the training or equipment says it is.

In 2001, Massachusetts schools were required by legislative mandate to provide engineering education in the K-12 curriculum for all grade levels. At the time, efforts to meet this requirement underscored the lack of available research-based curriculum, professional development, and other components necessary to establish preengineering in K-12 education. The Texas legislature followed suit eight years later. Interestingly, Jacob Foster works for the Massachusetts Department of Elementary and Secondary Education, and Rogers et al. (2010) examine the current state of K-12 engineering in Massachusetts—after ten years of development the authors describe the implementation of engineering education as being successful yet slow to develop (p. 181).

Both the Texas legislature approval of the new science and mathematics 4×4 high school graduation requirements, and the Texas Education Agency (2009) revision of TEKS—the content standards for courses in the state inventory—resulted in the approval by the State Board of Education of a new engineering course that counts as a new science category for graduation credit, which students have the option of taking in their junior or senior year. It remains to be seen if this new course creates any significant demand for preengineering curriculum, professional development, and other resources that specifically target the Texas standards. As part of the approval process the TEA contracted education consultants to compare the draft version of the engineering TEKS with the Massachusetts standard for precollege engineering education and state and national college readiness standards. The State Board of Education established a panel of experts to conduct a similar evaluation of the proposed preengineering course standards. Both of these examinations found that the new Texas engineering TEKS meet or exceed the requirements of the standards used for comparison.

A significant difference from Massachusetts' approach is that Texas is implementing engineering only at the high school level. When we were developing the Estacado Precollege Engineering Academy 10 years ago, we conducted a telephone survey of administrators in many of the larger districts across the state to determine (1) what engineering coursework, if any, was offered; (2) if any districts offered more substantive engineering programs with a sequence of coursework; or (3) if they offered any other significant engineering-based learning experiences, such as afterschool programs. More than 30 school districts responded to the survey; at the time, the number of districts providing engineering courses could be counted on one hand, and only three of these five districts had somewhat more substantive programs. In the ten years that have ensued, precollege engineering programs, courses with engineering content, and extracurricular enrichment learning opportunities have become common in districts around the state at the elementary, middle, and high school levels. These can be characterized in the same language that Rogers, Wendell, and Foster use to describe precollege engineering in Massachusetts: "much of what has been implemented across the state is widely varied in goals, methods, and quality" (p. 181).

Texas also has established the Mathematics, Physical Science, and Engineering teacher certification (SBEC, 2004); however, until recently there were no undergraduate programs offering engineering coursework to pre-service teachers for this certification and no established graduate programs for in-service teachers beyond professional development workshops offered for continuing education credits. One obstacle regularly encountered in identifying coursework appropriate for pre-service teachers is that engineering courses typically require significant mathematics and science prerequisites, which can pose an obstacle to non-engineering students. Recently the UTeach program at the University of Texas in Austin was awarded $12.5 million by the National Science Foundation (NSF) to develop engineering tracks for both in-service and pre-service K-12 teacher certification in which students in UTeach engineering cohorts will earn engineering degrees. Texas Tech is offering a new interdisciplinary degree and certification program in which pre-service and graduate students choose among a number of engineering courses that are not laden with prerequisite requirements. These courses generally emphasize the engineering design process or other requirements in the new engineering TEKS, such as ethical or social responsibilities of engineers, or various aspects related to career paths in different engineering disciplines.

Issues Related to Precollege Engineering Curriculum

Project Lead the Way and Infinity Project are two curricula that are being widely adopted in Texas schools, but there has been little substantive research that demonstrates how, or if, these curricula help students to develop the "habits of mind" that the NAE identifies as an engineering skill set with potential to contribute to a technically proficient citizenry for the 21st century (p. 5), or if these curricula are effective cross disciplinary vehicles for teaching standards based concepts in science, math, technology, and other academic subjects, as the NAE also suggests.

Project Lead the Way was developed through a consortium effort with the participation of a number of universities and the Infinity Project was developed as a collaborative effort between Texas Instruments and Southern Methodist University. Both of these curricula require schools to make a significant upfront capital investment in proprietary lab equipment and technology. One drawback to this approach is that this reliance upon proprietary technology and laboratory equipment can be extremely intimidating for teachers who are trained to use the equipment and teach engineering during sessions lasting from one to two weeks during the summer. Our experience with the TTU Pre-college Engineering Academy and other schools has been that teacher turnover often renders the equipment useless until another teacher can be trained. Proprietary technology also has a limited life span requiring an ongoing replacement cycle that can be financially burdensome.

This discussion is not intended to critique the design or value of these curricula, because they have a history of large scale implementation and are well recognized for providing students with learning experiences involving engineering concepts and skills. It is important to note, however, that no matter how widely adopted these curricula are in Texas, they currently are not automatically accepted for transfer credit among high schools, and many universities do not consider them for admission. In Texas, because these curricula are not directly tied to specific course standards in the TEKS, they have either been offered as Innovative Courses in Texas—which will no longer be allowed under the revised Public Education Information Management System (PIEMS)—or for local transcript credit.

Since they are offered as local credit courses, there is no guarantee they will be accepted for transfer or for enrollment by postsecondary institutions. Brophy, Klein, Portsmore, and Rogers (2008) and Rogers et al. (2010) indicate that accreditation problems and a lack of acceptance of precollege engineering coursework for admission to universities is a pervasive problem and suggest this lack of acceptance reflects how engineering is viewed by universities themselves in relation to the sciences and mathematics. Whether this value assessment of universities is real or inferred, the discussion suggests that accreditation is a significant obstacle to integrating engineering into K-12 education.

Development of the TTU FRAME Model

The Texas Tech T-STEM Center is part of the Texas STEM Initiative, which is a key component of the Texas High School Project (THSP), a $180 million public-private initiative committed to increasing graduation and college enrollment rates in Texas. Partners include the Texas Education Agency (TEA), Bill & Melinda Gates Foundation, Michael & Susan Dell Foundation, Communities Foundation of Texas, and industry partners. Resources dedicated to the THSP support new and redesigned high schools, educator training and development, and specific college preparatory programs. Some goals and outcomes addressed by this STEM initiative are as follows:

- Establish 50 Texas STEM Academies in areas of high need across the state, each year producing 3,500 Texas high school graduates from diverse backgrounds prepared to pursue careers in STEM related fields
- Create 7 Texas STEM Centers to support the transformation of teaching methods, teacher preparation, and instruction in STEM fields with research-driven methods and resources
- Establish a statewide best practices network for STEM education to promote broad dissemination and adoption of promising practices to improve math and science performance of all Texas students.

Each of the T-STEM centers supports STEM education in Texas schools through professional development for teachers, developing research-driven STEM curriculum, and other research and support activities. The centers also work closely with the T-STEM academies to help provide unique STEM learning experiences to students with project-based instruction, teaching across the curriculum approaches, and other innovative methods for teaching and learning in STEM areas. Academies are required to select their students by a lottery system that ensures a demographic cross-section of students in the district. All of the curriculum developed by the centers and implemented by the academies must incorporate a hands-on, project-based approach to engage students in learning. Each of the centers is expected to develop an area of specialized research and development. The Texas Tech T-STEM Center specializes in precollege engineering and has committed significant effort and resources to addressing many of the problems discussed here and in the literature regarding K-12 engineering.

Description of FRAME

Instead of developing an engineering curriculum tied to certain equipment or specific science and mathematics content, our approach was to develop the TTU engineering design FRAME model, which provides teachers with tools to manage design projects and use project lifecycle conventions for documentation and various project phase activities to assess and evaluate student learning, as well as a framework to teach course content. One advantage of this approach is that it provides a framework for developing design problems that specifically address required content for any course under the TEKS. Projects may also be developed to engage students in designing solutions to real world problems, or as a service project within their communities. The model establishes overarching questions, activities, and outcomes and goals for each project phase to give students a structured approach to resolving poorly defined or open-ended problems.

One problem with project-based learning is that, because relatively few teachers are exposed to project lifecycle concepts as part of their education, they often manage hands-on projects by allowing students to begin construction of an artifact without modeling or other *proof of concept* activities that characterize the engineering design process. The FRAME model requires students to articulate and justify all of their design choices, as well as predict the performance of any product or artifact that is developed during the course of the project—before anything is built.

A unique feature of the FRAME model is that it employs a heuristic guide to help teachers and students engage in a more complete consideration of constraints and issues that must be addressed during each phase of the project. The heuristic model also helps them understand the role of project documentation and presentations using conventions appropriate for each phase of the project lifecycle. The documentation not only helps students articulate a history and rationale for their design decisions, but documentation allows the opportunity for K-12 teachers to submit project documents for feedback from Texas Tech faculty and staff.

While this approach is significantly more difficult to implement, it has a number of advantages with regard to many of the issues discussed here. It provides more flexibility for the kinds of design projects available to provide engaging teaching and learning experiences and still allow the teacher to teach the content required by the course standards. More significantly, the FRAME model directly addresses the TEKS established for engineering.

One of the authors, John Chandler, served on the committee that wrote the engineering standard adopted by Texas at the request of the State Board of Education (SBOE). Other members of the committee were K-12 teachers and administrators, engineering practitioners from industry, and other representatives of higher education. The standard developed by the committee was the result of many passionate discussions about the kinds of content, skills, and processes that we could agree were essential knowledge and skills for engineering education—and which also could be offered within the existing structure, conventions, and capabilities of the school system. There was much discussion regarding the inclusion of rigorous academic content in both mathematics and science, developing a structure that reflected the conventions of university engineering education, and how various engineering concepts fit within the conventions and constraints of K-12 education.

The resulting standard is used not only to define academic content for K-12 engineering education in Texas for the next ten years, but will also guide development of curriculum resources and textbooks that will be adopted by Texas schools. The committee was forced to disregard many deeply held beliefs and expectations for precollege engineering education when faced with realities of the K-12 environment and how education standards are implemented in practice. The TEKS emphasize knowledge and skills specific to engineering design process and excluded specific academic content. Instead the assumption was that students coming into the course would have already taken 2–3 years of math and science courses under the Texas 4×4 plan for graduation. The course is intended to provide a capstone experience for students to apply previously learned academic content.

The committee members came to recognize that any academic content it might require could have the effect of limiting the kinds of design projects that would be possible. For example, if the standard included proficiency with certain biology concepts, then design projects that emphasized physics—a rocketry project, for instance—might not meet the requirements of the standard. The standard was written so as not to limit the type and scope of design projects available for project-based teaching and learning, but to require classroom implementations to adhere to a rigorous standard for the process itself. As the committee worked through issues regarding appropriate content for precollege engineering education and began to focus more on a design process approach, it began to realize that wording of the standard would have to accommodate various design process models, because of problems arising from the lack of substantive K-12 epistemic experience, as suggested by Tate, Chandler, Fontenot, and Talkmitt (2010):

> The literature suggests two basic approaches for representing engineering design: a phase-based, lifecycle-oriented approach; and an activity-based, cognitive approach. While these approaches serve various teaching and functional goals in undergraduate and graduate engineering education, as well as in practice, they tend to exacerbate the gaps in P-12 engineering efforts, where appropriate learning objectives that connect meaningfully to engineering are poorly articulated or understood. This is not to suggest that the realms of higher education and industry are immune from conflicting perspectives and agendas regarding engineering education. However, epistemology provides a common lens with which the topographies of various stances can be brought into focus and examined; whereas, no such context exists in P-12 engineering.

The committee also recognized several disconnects between the structure and expectations for K-12 and higher education. For example, a common engineering education experience requires almost two years of prerequisite course work in the sciences (usually with emphasis on physics) and a mathematics course sequence through differential equations calculus. It is also not uncommon for engineering education to emphasize theoretical understandings of thermodynamics, statics, fluids, and other courses commonly referred to as the engineering sciences. In some programs, students may only encounter the engineering design process during a capstone class in their senior year.

Conclusions

This discussion aims at identifying some of the issues and problems that may impede implementation of engineering education in the K-12 environment. Specifically, the lack of a tradition for engineering in the K-12 curriculum results in significant gaps in standards and policy, experience with classroom implementation—as well as support infrastructure that exist for academic disciplines which historically have been part of the K-12 experience. Among the systemic

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components that would provide more consistent and effective K-12 engineering implementation are the following:

- Cohesive standards and policies to provide a framework for systemic development of educational resources for precollege engineering, including standards for assessment and evaluation
- Cohesive efforts across institutional boundaries for collaboration and as a means to address problems with conflicting agendas and perceptions
- Infrastructure mechanisms and standards for pre-engineering teacher certification and professional development, including professional organizations for teachers
- Research and a body of literature for preengineering with methods and epistemic tradition suited to exigencies of K-12 education.

Until we begin to address these gaps in a systemic fashion, the quality of the educational experience we provide to students and the content knowledge and pedagogies of teachers in preengineering will remain extremely uneven, with no research-driven, generally accepted basis for assessment and evaluating effectiveness of implementations. The current state of precollege engineering has no epistemic foundation to provide the common language, shared concepts and historical perspective found within the traditions of science, mathematics, and other disciplines that are well established in K-12 education.

Efforts to view the growing experience with K-12 engineering only through the lens of engineering education have been inadequate because these approaches typically fail to meaningfully account for exigencies specific to K-12 education. Rogers et al. (2010) suggest researchers adopt a range of methodologies and theoretical lenses from among the many disciplinary traditions conducting K-12 research. Given the conceptual disconnects between colleges of engineering and K-12 education discussed here, a growing trend toward teaching STEM as interrelated knowledge and skills, an interdisciplinary approach has obvious merit—not just to inform research, but also because many disciplinary interests intersect in the K-12 STEM classroom as an increasingly integrated STEM paradigm emerges. There is growing conviction that substantive STEM reform must be inclusive, allowing participation and ownership by all the stakeholders. This emerging STEM paradigm emphasizes the interrelatedness of concepts from science and mathematics, which find application in engineering and underpin the technologies used by in technical workforce and among the citizenry as a whole. The potential of engineering education in the K-12 curriculum has created almost unprecedented development and participation in education reform by a wide-range of stakeholders representing both public and private interests. Perhaps we should heed the notion put forth by the NAE that precollege engineering could serve as a catalyst for significantly changing the way we educate our children, and that, if done right, might precipitate rethinking the whole system.

The attention being paid to putting the *E* in STEM at the K-12 level may very well result in questioning the conventions of higher education and result in more cohesion between secondary and post-secondary education, possibly creating new educational pathways into the technical workforce. New collaborative relationships are emerging in Texas to develop degree and certification programs for preengineering teachers at the University of Texas and at Texas Tech University. Both of these required collaborative development between the respective colleges of education and engineering of an appropriate sequence of courses for preengineering teacher preparation. In the past there had not been much reason for engineering colleges to work with colleges of education or other academic units engaged in teacher preparation. Instead, engineering colleges often had a tendency to focus inward on research and teaching the engineering sciences. Developing a cohesive set of standards for preengineering provides incentive that has heretofore largely been missing for engineering colleges to participate in teacher preparation or in other areas of K-12 service.

Certainly, there are many issues that policy and standards alone cannot effectively address. Studies conducted by the NAE (2002) indicate that a number of commonly held perceptions about engineering contribute to declining enrollments and interest in engineering programs especially among minority populations and women who are needed to increase diversity in the ranks of engineers. Massachusetts and Texas education systems have developed standards-based engineering education in their schools by mandate by their respective legislatures. Ten years ago when Massachusetts began to introduce engineering into K-12 education, the process of developing implementations in schools was hampered by a lack of curricular development, teacher training, and other resources. Nine years later, significantly more curriculum and other resources for precollege engineering are available, but many of these preengineering resources are not standards-based and do not meet accreditation requirements. There are also no widely accepted definitions of what activities, knowledge, and skills are appropriate for teaching and learning engineering in the K-12 environment, which complicates making informed choices regarding the quality and suitability of various curricular resources and professional development for teachers.

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